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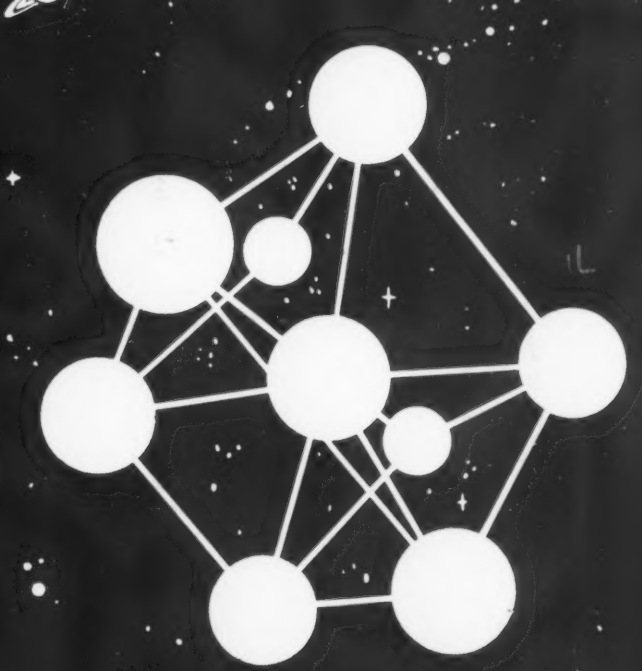

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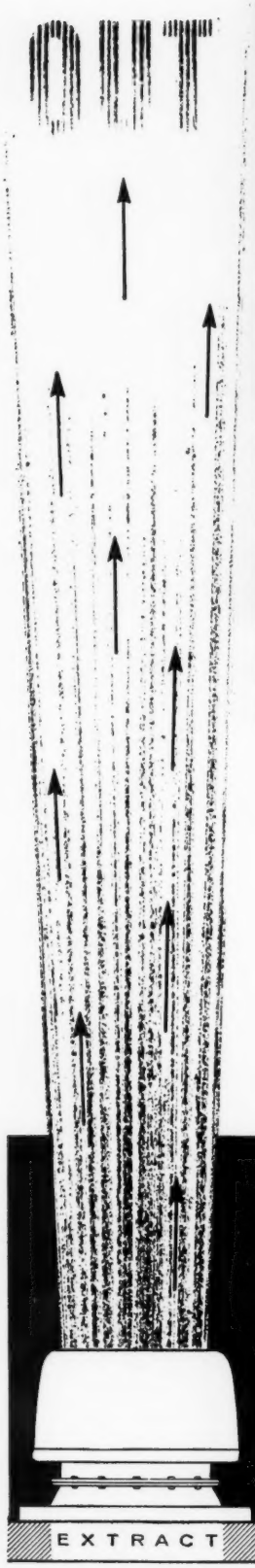

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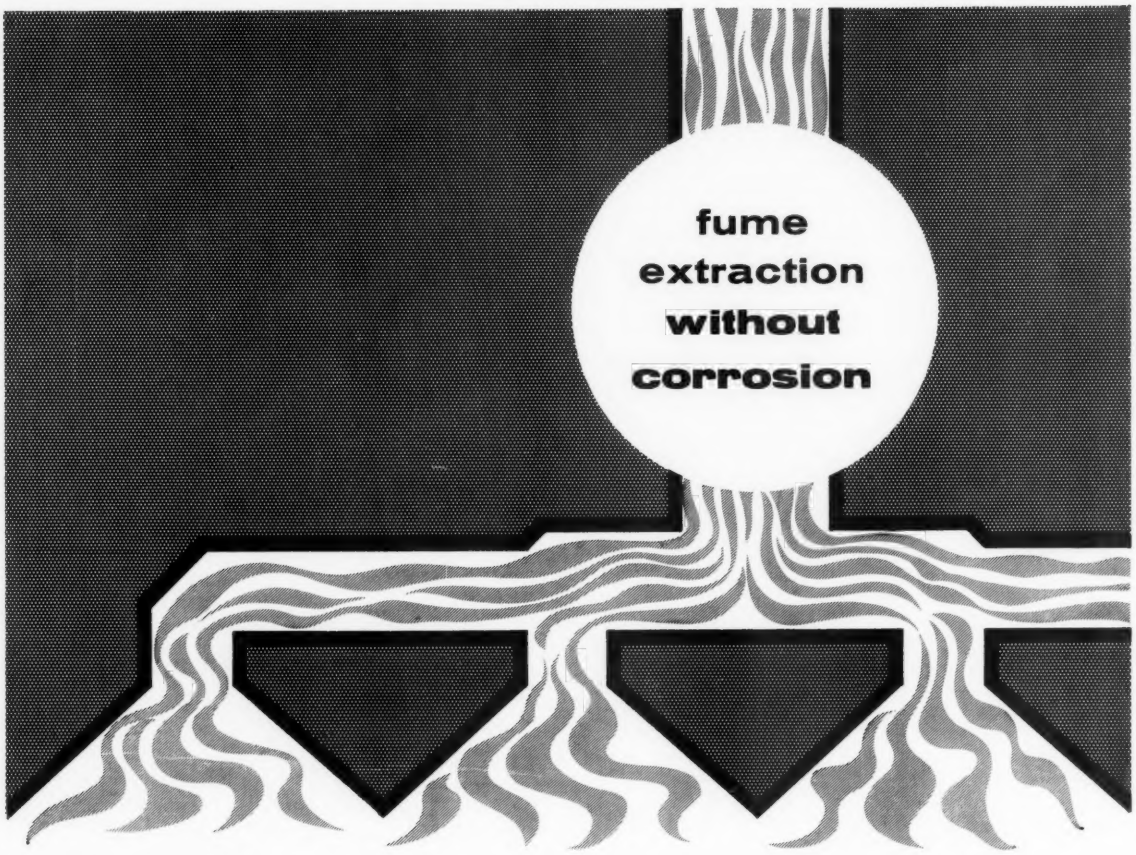

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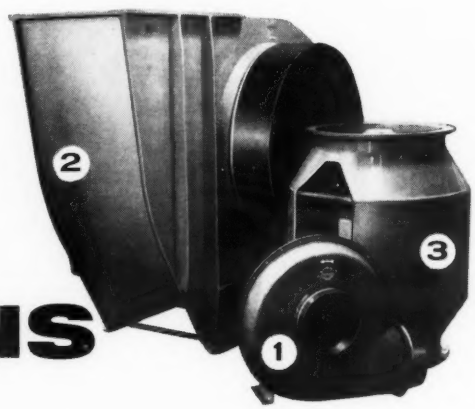

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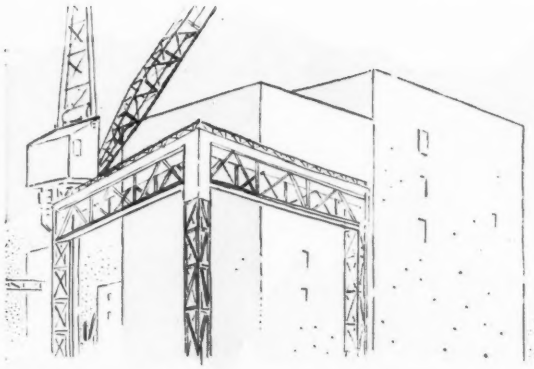

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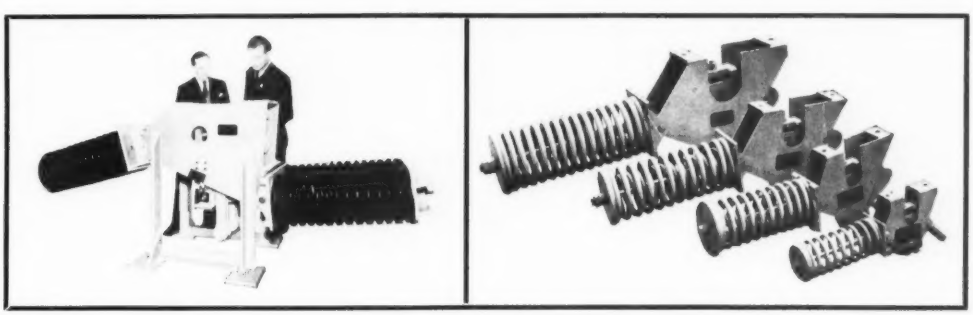

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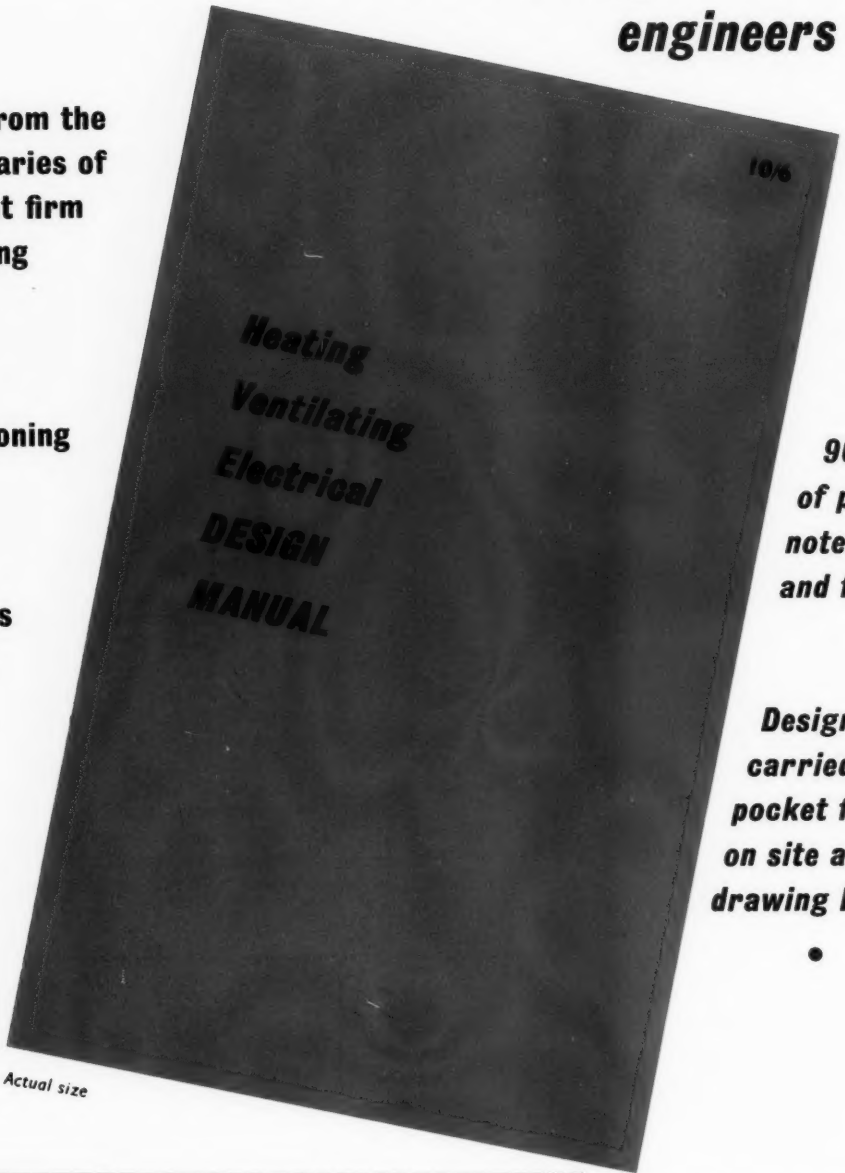

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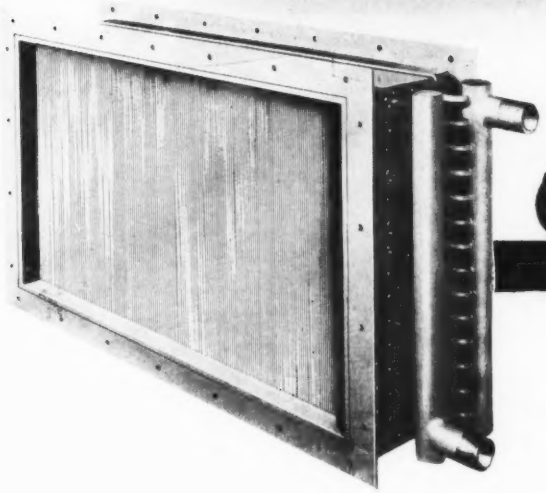

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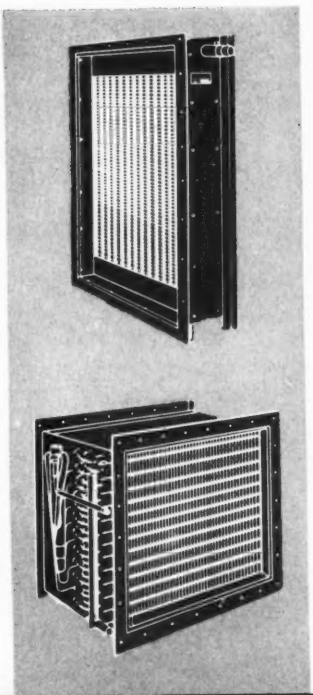

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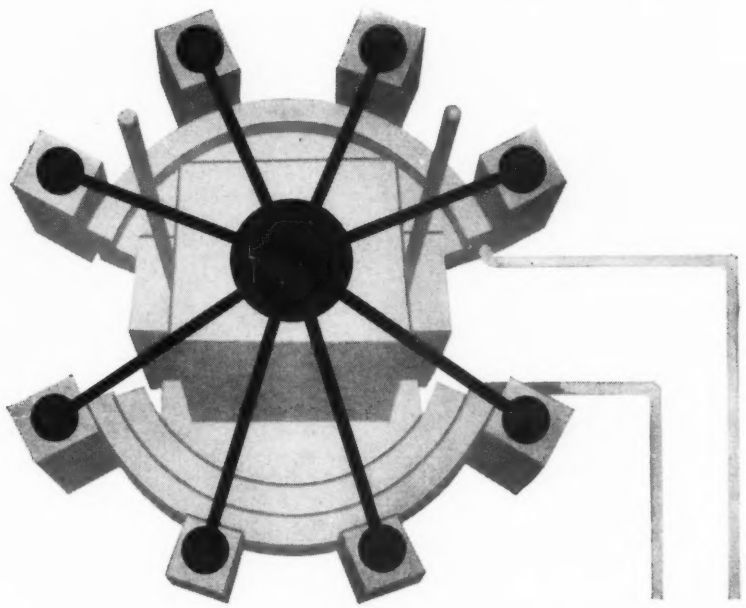
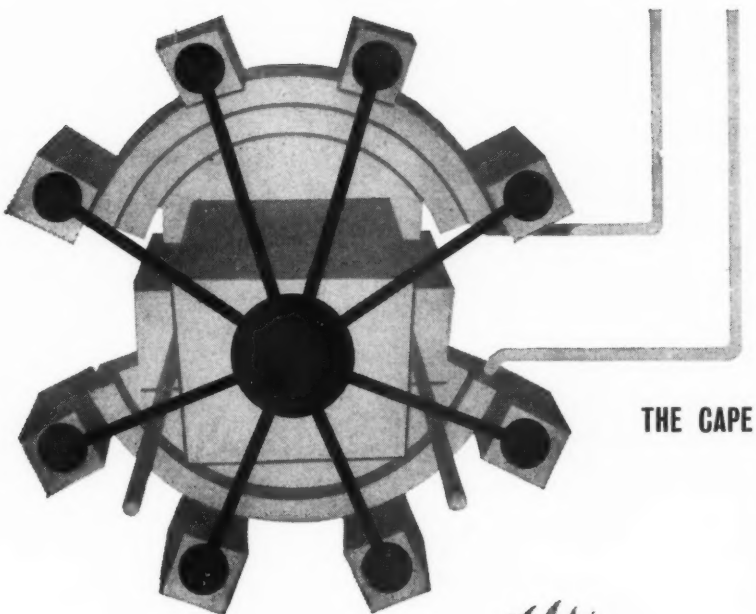


BERKELEY—a challenge to insulation



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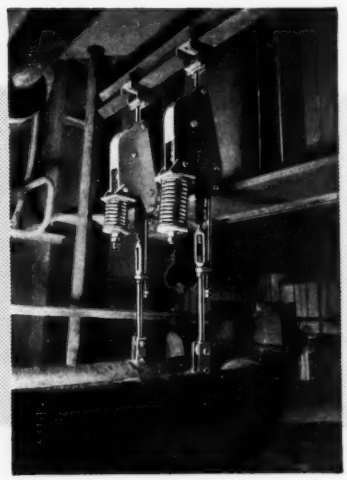

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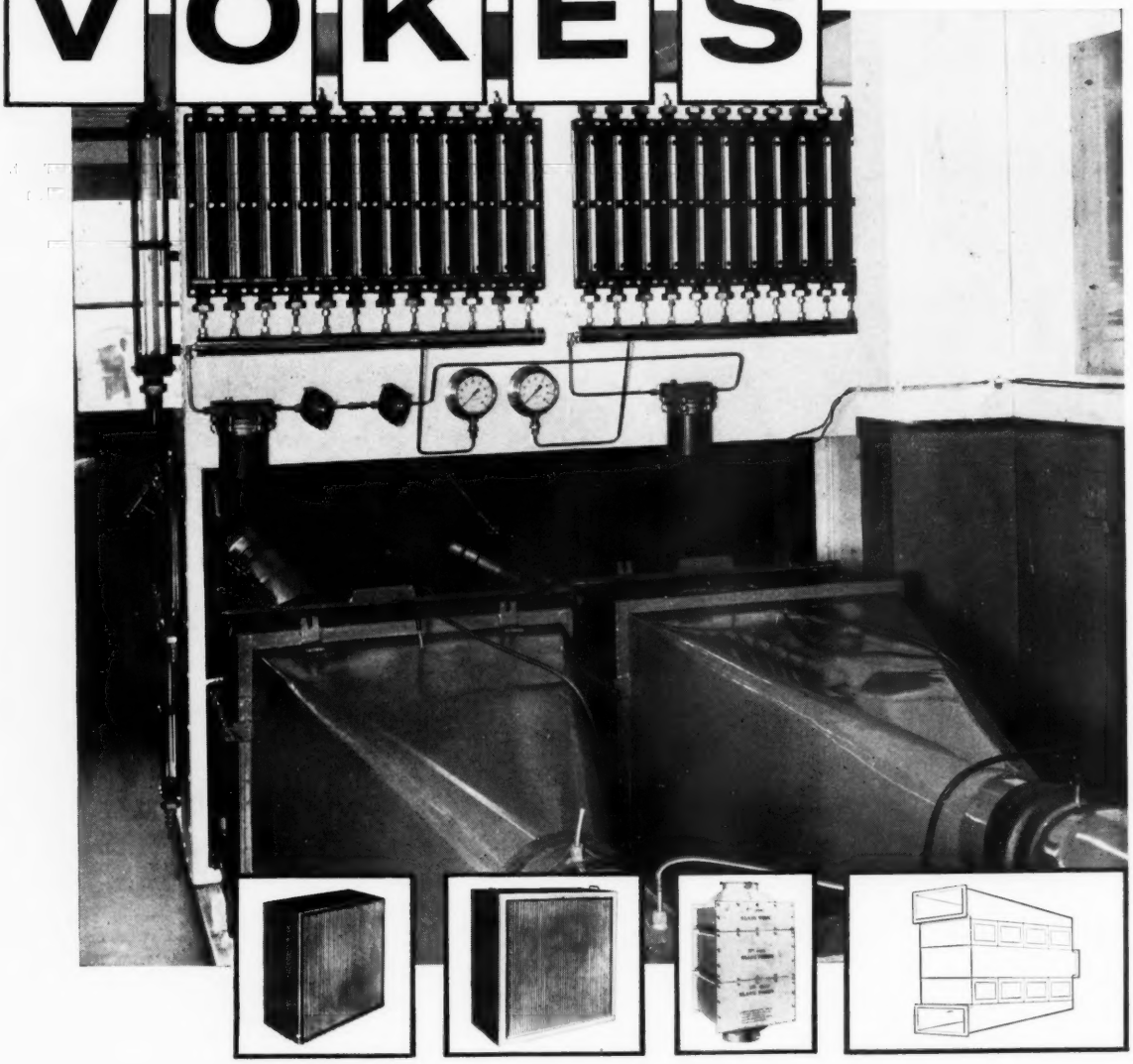

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BERYLLIUM

by M. K. McQuillan and T. W. Farthing

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Beryllium Research

The main aims of beryllium research are to give the metal more uniform room-temperature ductility and to improve its workability at higher temperatures by eliminating minima in the ductility/temperature curve.

In order to make beryllium satisfactorily ductile at room temperature the principal difficulty to be overcome is that of cleavage fracture on the basal plane. Reasons for the observed behaviour may be of two basic kinds, one deriving from the fundamental properties of metallic beryllium itself and one due to impurities. If the fault lies with the metal, it must be assumed that the interatomic bonding within the planes on which premature fracture occurs is very much stronger than that between them, that is, the crystal has a layered structure similar to that of graphite, involving partially directed bonds and implying some departure from ideal metallic behaviour. If this type of explanation is true, the only way in which the situation can be improved is to alloy the beryllium with a metal which can enter into solid solution with it and by thus changing its electronic structure modify the type of bonding existing in the metal crystal, or even the crystal structure itself. If, on the other hand, impurities are playing a major role—as they could, for instance, by raising the temperature of the ductile/brittle transition undergone by many metals at low temperatures or by forming oxide layers at the grain boundaries—the choice lies between removing the impurities altogether or eliminating them from the metal crystal by a precipitation process, such as can be achieved by taking advantage of a change of solubility with temperature, or, alternatively by adding an alloying element which will combine preferentially with the impurity.

Although room-temperature brittleness in beryllium could be an inherent property of the metal, it is difficult to envisage any fundamental characteristic of the beryllium crystal which could give rise to the complex ductility/temperature relationship observed, and there is growing confidence that this is an impurity effect. Again the choice of remedy lies between purification and precipitation of the impurities by heat-treatment or alloying.

This article is continued from page 164 of April issue.

Modification

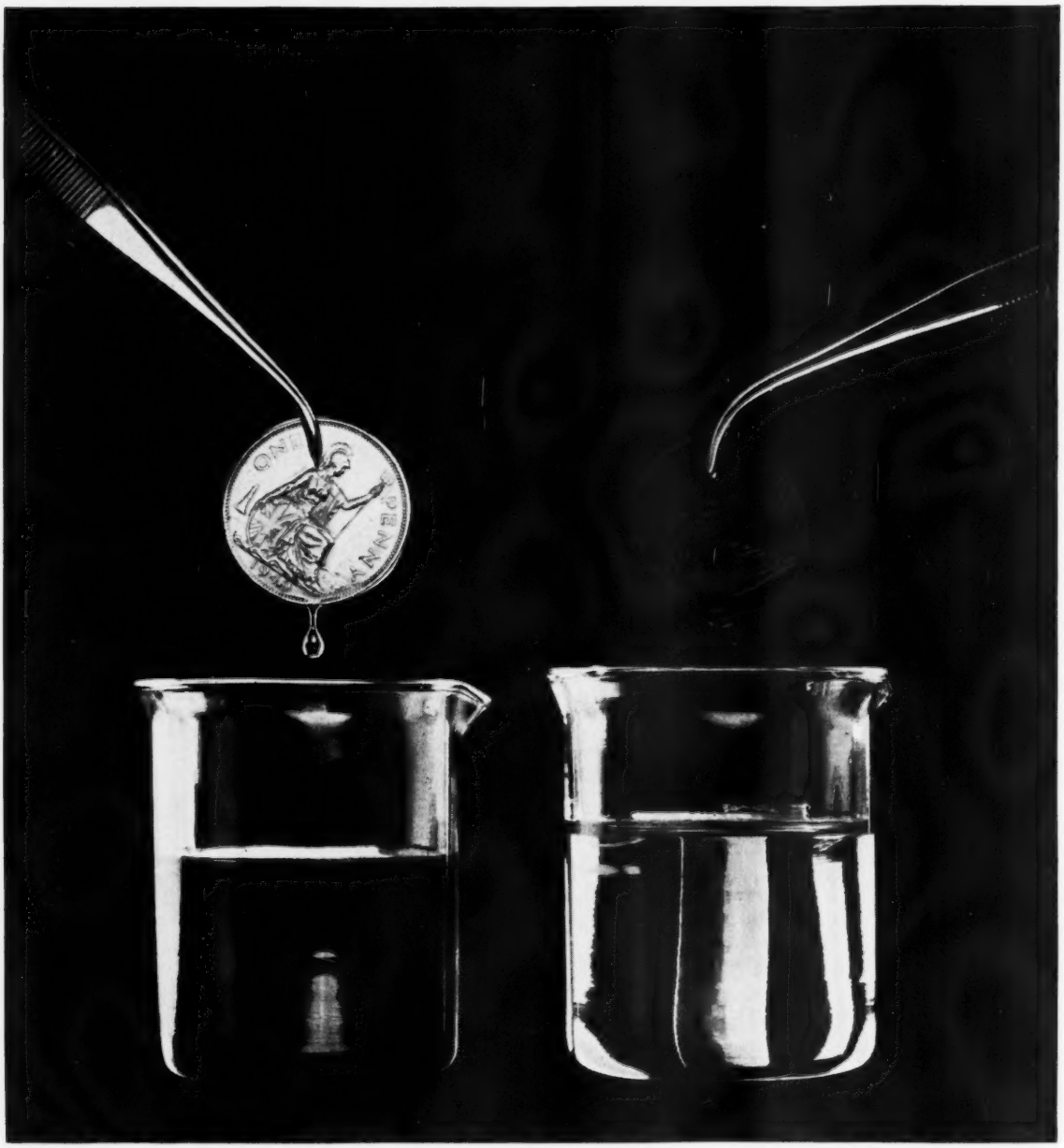
Consideration of the atomic properties of beryllium suggests that attempts to modify the electronic nature of the metal are unlikely to be rewarding. The beryllium atom is very small, having an atomic radius of 1.125 Å. Normally it is observed that extensive solid-solubility between one metal and another occurs only when the atomic radius of the solute element differs from that of the solvent element by not more than 15 per cent. of the atomic radius of the latter. Consequently little solubility in beryllium can be expected from the majority of elements, since all but a few have atomic radii well outside the favourable range. The tendency will rather be to form intermetallic compounds, more particularly as beryllium is one of the more strongly electropositive metals —a fact which favours compound formation with electronegative elements. The chance of dissolving a proportion of a substantial alloying element in beryllium sufficient to modify appreciably the electronic characteristics of the metal seems thus to be very small. In fact only copper, palladium, nickel, cobalt, and silver have any appreciable solubility in beryllium, and even for these elements the range of solid solutions is too limited to offer much hope of influencing the fundamental nature of the metal. Attempts have been made to stabilize, at lower temperatures, the body-centred cubic structure that beryllium is reported to adopt at temperatures near its melting point, by adding the more promising alloying elements, and though it might have been expected that without more extensive solid-solubility than has yet been found there would be little likelihood of success, recent work indicates that it may in fact be possible to retain the high-temperature structure at temperatures approaching the range suitable for hot working. Some consideration is also being given to the possibility of stabilizing this structure by the application of high pressures.

Purity

Any aspects of the behaviour of beryllium which are due to impurities have a considerably greater chance of being modified. Methods of purification under investigation include distillation, iodide refining, zone refining, electrolysis, and electron-beam melting. These have not yet produced a form of beryllium which is free of processing difficulties, and it is probable that the embrittling mechanisms operating involve very small quantities of impurities.

In attempting to solve the impurity problem by precipitation rather than purification, the fact that the solid solubility of most elements in beryllium is very limited helps rather than hinders, as small additions of alloying elements having a high affinity for the common impurities can be added without appreciable modification of the beryllium itself. A full exploration of the

Shell demonstration



Two clean, bright pennies are placed in beakers of oil, of equal performance level, one Shell Garia Oil 21, the other a conventional cutting oil containing sulphurised additives. After three hours at room temperature one penny is still bright and stain-free, the other heavily stained with black copper sulphide. The bright penny is from the beaker containing Shell Garia Oil 21, the blackened one from that containing the conventional oil. While these were just pennies they could have been bronze bushes in your machine tools—stained in less than half a shift. Sulphur is essential in heavy-duty cutting oils. Special additives in Shell Cutting Oils protect your machine tools and yet allow the sulphur to do its job. *Write for the book "Selecting Your Cutting Oils" to Lubricants Department, Shell-Mex House, London, W.C.2.*

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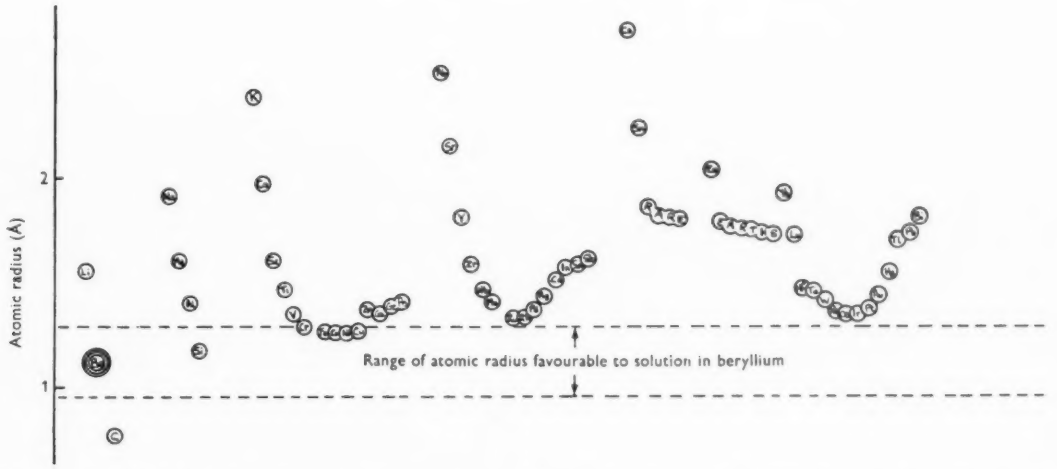

Fig. 2. Atomic radii of the metallic elements. Only silicon, iron, cobalt, nickel, and copper fall within the range favourable to solution in beryllium.

possibilities of precipitation by alloying additions and by heat-treatment forms an important part of present-day beryllium research. Hydrogen, oxygen, nitrogen, iron, aluminium, and silicon have all at some time been suggested as the impurity responsible, and current work may be expected to define the part played by these elements more accurately.

Some of the research effort available for beryllium is being devoted to a study of dislocation movements in beryllium crystals, which should clarify the reasons of the room-temperature brittleness of the metal and establish the mechanisms by means of which impurity elements can influence its deformation behaviour. The knowledge that, given a satisfactory grain-structure, beryllium can exhibit good ductility has also encouraged efforts to bring about the desired structure in material as cast.

The Future of Beryllium

Though it has required the stimulus of atomic energy to produce the effort necessary for the full industrial development of beryllium, the metal might well find other applications. The most obvious possibility is in the aircraft industry, which could take advantage of its extreme lightness and rigidity. The same qualities may also find some applications in missiles. Less dramatic uses are found in gyroscopic components, which require very high rigidity plus dimensional stability, and also in X-ray sets, for which beryllium, being transparent to X-rays, is an ideal window material. This last application was the first industrial use of metallic beryllium.

As with so many other of the less common metals, the future of beryllium depends on its availability, its cost, and the extent to which its fundamental disadvantages can be overcome. With its unique combination of desirable characteristics, there is little doubt that a ductile and workable form of beryllium would find important applications, even if it remained very costly; but it remains to be seen whether ductile beryllium will ever be offered as an engineering material.

Although it might be argued that, if a very high degree of purification is necessary in order to obtain satisfactory room-temperature ductility and the required high-temperature properties, the full exploitation of beryllium by engineers is unlikely, it must be remembered that in the case of hafnium the dependence of its ductility on such an expensive refining process has not prevented its use. It is true that when the costly iodide-refined titanium and zirconium were the only available ductile forms of these metals no engineering applications were found for them, but the engineering applications which created the need for their specific properties did not take place until after a cheaper commercial process for the manufacture of the ductile materials had been discovered.

The nature of its processing inevitably makes beryllium expensive but increased production can be expected substantially to reduce price. Ten years ago the American price for beryllium billet was over $100/lb, but a demand for about 50 tons a year quickly reduced this to $47/lb. Comment on the trends of British prices would as yet be premature, but they are not expected to exceed current American prices. In making comparisons of cost it must be remembered that beryllium is appreciably lighter than other metals, and that the figure used for most comparative purposes should be the cost/unit volume; on this basis beryllium appears in a much more favourable light. Moreover, full-scale industrial exploitation would bring about even greater price reductions than have so far occurred.

What is now needed is a better understanding of the behaviour of the metal itself and of its toxicity so that processing can be simplified and cheapened. With advances in metallurgical and medical knowledge it can be hoped that within the next few years it will become possible to assess the future of beryllium far more accurately than can be done today. △△△

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Book Reviews

Elementary Introduction to Nuclear Reactor Physics, by S. E. Liverhant. Published by John Wiley & Sons, Ltd., London and New York, 447pp. Price 78*s*.

Before reviewing the book I asked myself: "Towards what sort of readership is it directed?" This question, I found, was answered in the preface, which starts "This book is intended to serve as a textbook for an undergraduate course in nuclear reactor physics." Armed with this knowledge, I put myself in the position of a student of such a course, and against this background I attempted to assess the value of the text. Now I must confess that I have read, or at least attempted to read, quite a number of books written by authors who claimed to have a similar readership in view. In every case, I also confess, I soon became bogged down in a lot of stodgy mathematics. This book is different, I am glad to say. I could see that after just a few pages. The author, an associate professor at the Maritime College, New York State University, has aimed at giving an elementary but coherent account of the branch of physics involved in the study and design of nuclear reactors, and it was based on a course which has stood the test of seven years of lectures. Liverhant has avoided a too-detailed and mathematical treatment, but has also eschewed a shallow and purely descriptive exposition. This middle course has had the required results. The reader requires only calculus and an elementary acquaintance with differential equations. Frankly, I have seen no other book in which so much has been covered in such a painless way. The book opens with nuclear structure and radioactivity, nuclear forces and binding energies, threshold energies of nuclear reactions, neutron reactions and cross-sections. In section five we meet nuclear fission, and the following sections give us thermal neutrons, nuclear chain reactions, neutron diffusion, critical equation, non-steady reactors and reactivity. The last three chapters are concerned with the interaction of radiations with matter, and the problems of radiation detection and measurement, and health physics. There are several appendices on mathematical topics. The whole book is extremely well conceived, the print is clear, and the illustrations excellent and appropriate. Each chapter has a selection of problems (with answers!) and a useful bibliography. This volume is clearly not for the expert in nuclear reactor physics, but it commends itself highly for engineers and others who require a sound background knowledge of the subject. To these readers will be especially useful the worked examples, since they help to overcome the one big hurdle which usually faces students —the approach to numerical problems. I have tried hard to find some faults in this book—I have been unsuccessful. So I can only be enthusiastic about it, and I am certainly convinced that it is a much-wanted and extremely useful work which will find an enthusiastic readership.

F. R. PAULSEN

Field Computations in Engineering and Physics by Professor Alexander Thom and Dr. C. J. Apelt. Published by D. Van Nostrand Co., Ltd. (London, Toronto, New York, Princetown, New Jersey). Size 6 in. × 9 in. × 165pp. Price 30*s*.

Engineers who can look back a good many years may recall a famous writer of engineering and mathematical textbooks, Professor Perry, who said "Happy is the man who is a mathematician as well as an engineer" and only readers of that enviable category will be able to make full use of this masterly work by Professor Thom and Dr. Apelt. These able authors are gifted far above normal in the two widely different faculties, mathematics and engineering, and it is to be regretted that they did not provide a little more for ordinary mortals in the introduction to this fund of valuable technique to the research worker whether he be mechanican, a hydrodynamicist or a nuclear engineer. The book describes Professor Thom's "Squaring Method" for the numerical solution of partial differential equations in two dimensions and it is claimed that this is the simplest, fastest and most efficient technique for obtaining numerical solutions to all types of field problems. It is also stated that practically all the methods described have been programmed for the digital computer in the Computing Laboratory at Oxford University. With the ever increasing applications of physical science more rapid calculation will become essential, and the authors in their concluding chapter give us this revealing information:—"The solution of say, Poisson's equation in a rectangular boundary may be completed in a time to be measured in minutes, but to undertake by hand the solution of a very ordinary looking problem involving a non-linear equation may be a very formidable task. Kawaguti (1953) states that a solution of the flow past a circular cylinder at $R=40$ took him $1\frac{1}{2}$ years working twenty hours per week," Could there possibly be a better illustration of the unremitting patience of some research workers? And indeed, this work, the product of much research by the authors, especially Professor Thom, will materially help to lighten the burden of applied mathematicians and physicists and also engineers who have the necessary mathematical background to study its informed pages.

D. S. WATT

Kinematics of Nuclear Reactions by A. M. Baldin, V. I. Gol'danskii, I. L. Rozenthal. Translated by W. E. Jones. Pergamon, 303pp. Price 42*s*.

This volume first appeared in Moscow in 1959, and its English Translation issued at the beginning of 1961 is to be welcomed. In spite of this relatively short interval, the authors, in their preface to the English edition, reveal that since the initial Russian publication their views on certain topics have changed. This is the best indication of the rapid advances taking place in the subject, and emphasizes the need for rapid publication. The work is concerned with theoretical nuclear physics, and its scope is essentially mathematical in nature. A short introduction into some relativistic concepts is followed by sections concerned with the kinematics of interaction of several particles, including photon interaction. The book then deals with the scattering matrix and Dirac's theory of transformation, and their application in theories of nuclear reactions. Items discussed include collision of particles possessing spin, polarization and photon reactions. The authors have omitted a number of mathematical presentations, on the grounds that the book is intended primarily for the experimentalist. The reviewer would hesitate to present the contents of this volume, in its present form, to the average experimenter in Britain, though it is most welcome for the theoretical physicist. The publisher has inserted a note explaining the need to produce the text by non-letterpress setting and photolithography, to ensure speed of reproduction and a cost which is not excessive. This form of printing detracts from the appearance of the volume, and better characters might be desirable. But the general layout and binding are well up to standard, and the price is very reasonable, particularly in view of the necessarily limited readership. I. R. Maxwell has made a welcome gesture in paying the usual author's royalty to the Russian authors in the hope that the Soviet authorities will eventually reciprocate, and deal more kindly with British authors whose books they translate and publish. In conclusion one can recommend this volume for detailed study by the specialist. The experimental worker is unlikely to profit adequately from a rapid perusal.

The 1961 edition of **The Engineers Buyers Guide** has now been published. It contains sections devoted to exhibitions, associations, institutions, addresses, U.K. agents for foreign firms, trade names, chemical plant, electrical equipment, engine parts and engines, machine tools and accessories, and sheet metal working machinery. △△△

Classroom and Laboratory

Arising out of a proposal by Dr. F. R. Paulsen, at a Council Meeting of the Institution of Nuclear Engineers, several hundred teachers of nuclear science were asked to report on simple apparatus and methods used or those which might be useful for practical demonstrations in instructional courses. The response was enthusiastic. From all parts of the world, from teachers in Universities, High Schools and Colleges, from research workers, manufacturers and public relations experts, have come many ideas. As a service to teachers, and also to other workers in nuclear fields, we are now publishing the many suggestions put forward. Each suggestion carries the identity of the person who put it forward, and also a reference number. The latter will facilitate enquiries sent in by readers requiring further information. Readers are invited to submit suggestions for inclusion in this feature

No. 43 Microdetermination of Silver by a radioactive reagent

Institut National des Sciences et Techniques Nucleaires, France.

Trace amounts of I131 are added to a solution of NaI(x mg/ml), and 1 ml of this is treated with $AgNO_3$ (25 mg/ml) to precipitate the AgI, coagulation being assisted by gentle boiling. Now HCl (5.5 mg/ml) is added to precipitate the remainder of the Ag as AgCl, which carries down the radioactive AgI. After boiling, the precipitate is filtered off and counted. Let the count-rate be d d.p.m./mg of I. Now 1 ml of the solution to be analysed is treated with 1 ml of the radioactive reagent, and boiled. The precipitate is collected in $BaSO_4$ formed by the addition of 1 ml of $BaCl_2$ (20 mg/ml) and 1 ml of H_2SO_4 (15 mg/ml). The precipitate is boiled, filtered and counted. Let the count rate be t d.p.m. This count rate corresponds to t/d mg of I, so that the weight of Ag in the sample is $(t/d)108x/127$ in mg.

No. 44 Uptake of radiophosphate by Animals

Reed College, U.S.A.

Into the tail vein of an anaesthetized rat 10 microcuries of radio-phosphate is injected. After 24 hours the rat is killed, and 1-2 g samples are taken from the following tissues: blood, bone, brain, kidney, liver, muscle, spleen, testes, and urinogenital system.

In each of nine 6 in. test-tubes the weighed samples are placed and left overnight with 2 ml of conc.HNO_3 in each tube. Next day the tubes are gently heated until the liquid is clear, a drop of octyl alcohol being added if frothing occurs. Each tube is cooled and 1 ml of 30 per cent. H_2O_2 added, then the tube is heated at 100° C. until the liquid is quite clear and yellow. After the addition of 2 ml of conc.HCl, each tube is heated until no more brown fumes are evolved, then neutralized with 6N NaOH to phenolphthalein. To each tube are then added in turn 1 ml of 0.2M Na_3PO_4 and 2 ml of 0.2M $Ba(OH)_2$. The tubes are centrifuged, and the phosphate precipitates are mounted in planchets for counting. This is done after drying under the lamp. After corrections for self-absorption, the count rates for all tissues are recorded, this being a measure of the tissue uptake of phosphate.

No. 45 Synthesis of the Tetrathionate Ion

Whittie J. McCool and Robert R. Hentz, U.S.A.

A 3 g sample of radio-sulphur (0.4 microcurie/g) is treated with 1.2M sodium sulphite and boiled for an hour. The end of the reaction is indicated by failure of the test for sulphite with $CaCl_2$, *i.e.*, no precipitate of $CaSO_3$ being formed on addition of 0.4M $CaCl_2$, to a test portion. The excess sulphur is filtered off, and the filtrate evaporated to 25 ml. To the cooled filtrate is added, with stirring, 11 g of iodine in 200 ml of pure alcohol. After five minutes the precipitate is filtered on a Whatman No. 42 paper in a Buchner funnel, washed with 10 ml lots of alcohol three times, and dried under the IR lamp, to constant weight. A 1.8 g sample of the radio-tetrathionate is dissolved in 50 ml of water, the pH adjusted to 6, and 50 ml of 0.27M sodium thiosulphate added. After a given time, 50 ml of 1.5M $BaCl_2$ is added, the precipitate of barium thiosulphate being washed, dried and counted. The count rate increases with reaction time, because of exchange of labelled sulphur atoms between tetrathionate and thiosulphate. Since the exchange times are short, the reaction time should fall within the range 0.5 to 60 minutes.

No. 46 Some Experiments on Uranium

R. E. Hein, U.S.A.

To a solution of 20 g of Na_2Co_3 in 200 ml of hot distilled water, 5 g of uranyl nitrate hexanitrate, and then 5 ml of 1 per cent. $FeCl_3$ are added with stirring, the solution being filtered through a loose-textured filter paper, the paper being washed twice with water. The filtrate is saved for recovery of uranium. The $Fe(OH)_3$ carrier precipitate is dissolved in 3N HCl and evaporated to dryness, then counted, the activity being compared with the beta count for 5 g of the original uranium salt.

The $FeCl_3$ residue is dissolved in 6N HCl (about 1 ml) and transferred to a small separating funnel with a few drops of 6N HCl. The extraction is made with three separate lots of 5 ml of ether. The aqueous layer is evaporated to dryness, and the activity again determined. Notice the small bulk of the residue, as the $FeCl_3$ has been removed in the ether. This experiment illustrates the preparation of carrier-free tracer by the use of a non-isotopic carrier and subsequent separation.

The uranium filtrate is acidified with 3N HCl, heated, and then rendered alkaline with ammonia

solution (6N). The precipitate of ammonium diuranate is filtered off, washed, and ignited to U_3O_8. The oxide is dissolved in a slight excess of nitric acid and recrystallized by careful heating to drive off excess liquid. The uranium thus recovered may be used over and over again.

No. 47 Radiometric Ore Analysis

Joe W. Tyson, U.S.A.

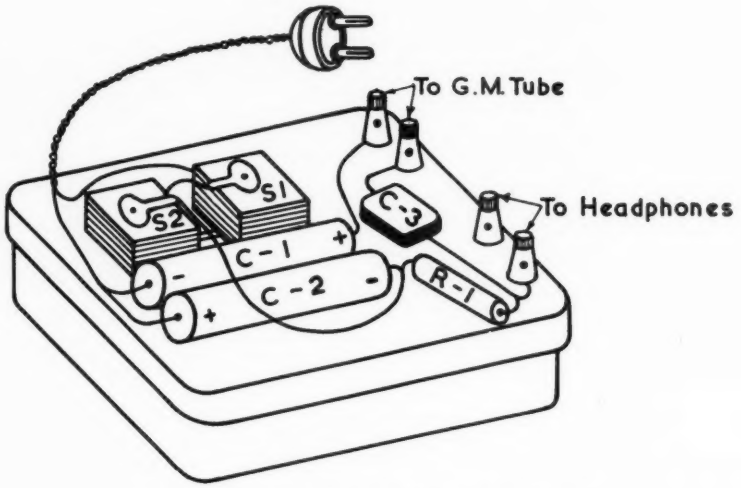
A number of ore samples with uranium contents over a fairly wide range will be required. Each sample is crushed, and a known mass placed in a planchet, thus reducing the "mass effect" of specimens with various sizes. The relative position of sample and GM counter is standardized, thus reducing the "mass effect" due to distance. Around the counter is placed a lead screen, and the net count rate is found. The count rates are plotted against the uranium content of the samples. The graph so obtained can now be used for the radiometric analysis of future ore samples.

No. 48 Uptake of P32 by a Slime Fungus

Joe W. Tyson, U.S.A.

Twelve grams of powdered oatmeal is ground in the palms of the hands, and poured into 400 ml of 2 per cent. Difco Nutrient Agar in a 1-litre flask. The solution is boiled, avoiding frothing.

Enough aqueous P32 to give an activity of 5.0 microcuries is added to a clean Petri dish, spread evenly by rotation, and then treated with about 15 ml of the prepared agar, then again rotated, cooled and placed under a GM counter so that several test counts may be made in areas of the plate. At least three areas should be counted. The same procedure is applied to several Petri dishes. The counted areas must be carefully marked on a disc of paper stuck to the bottom of the dish. A dried sample of the slime fungus *Physarum polycephalum* is placed on the surface of a sheet of wet blotting paper, encircled by dry Quick Quaker Oats, and kept moist for 3-4 days until the mould proves to be active. The mould is then transferred to the prepared agar plates. As the mould spreads over the surface of the agar, regular daily radioactivity counts are taken, the net c.p.m. for each area, and the total average activity being recorded. Notice must be taken of the variation of count rate from day to day for each site and for the average total activity, and this should be related to the decreased activity resulting from decay. A graph should be drawn showing the expected count due to half-life and the actual count determined.



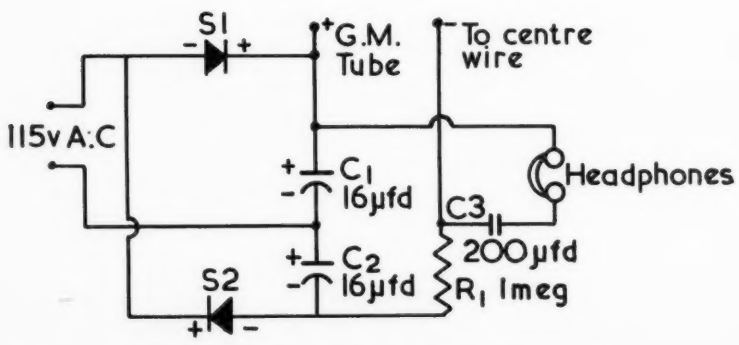
The simple GM assembly devised at the Oak Ridge Institute

No. 49 A simple GM Assembly

Oak Ridge Institute of Nuclear Studies, U.S.A.

The components required for this very simple instrument are: two 100 ma selenium rectifiers (S1, S2); two 16 mfd-150v electrolytic capacitors (C1, C2); one 0.0002 mfd blocking capacitor, 600v (C3); one 1 megohm ½w resistor (R1); one pair of headphones, 2,000 ohms; four terminals; one 300v GM counter.

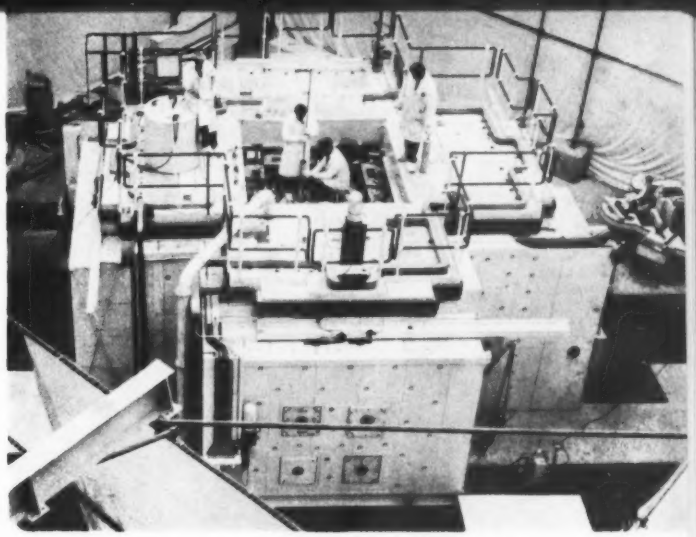
The components may be mounted, according to the wiring diagram shown, in a plastic sandwich box or even a wooden cigar box. All components except the headphones and tube are inside the box, the terminals being on the lid and projecting to the outside. The terminals for the GM tube should be clearly marked to ensure correct connection. The GM tube should have a protective shield of cardboard or plastic. △△△



Wiring diagram for the Oak Ridge cigar-box GM assembly

NESTOR

A new 10kW reactor at Winfrith



View of NESTOR showing loading of fuel element containing highly enriched uranium

CRITICALITY has now been achieved by NESTOR, the new 10 kW reactor at Winfrith. This Neutron Source Thermal Reactor, named NESTOR after one of Jason's Argonauts, will be used for experimental work in conjunction with sub-critical assemblies of nuclear fuels and moderators.

An alloy of highly enriched uranium and aluminium is used as fuel in NESTOR. This is arranged in the form of aluminium-clad plates placed in an annulus around a graphite cylinder; natural water is used both as coolant and moderator. Variations in the water level can be used for control purposes in addition to the control and safety rods. "Caves" can be provided in the shielding alongside and above the reactor to accommodate experimental assemblies. All the shielding can be dismantled and rebuilt to meet the requirements of the experimental programme.

Experimental data on graphite, natural water and heavy water moderated power reactors will be obtained from sub-critical assemblies placed next to NESTOR.

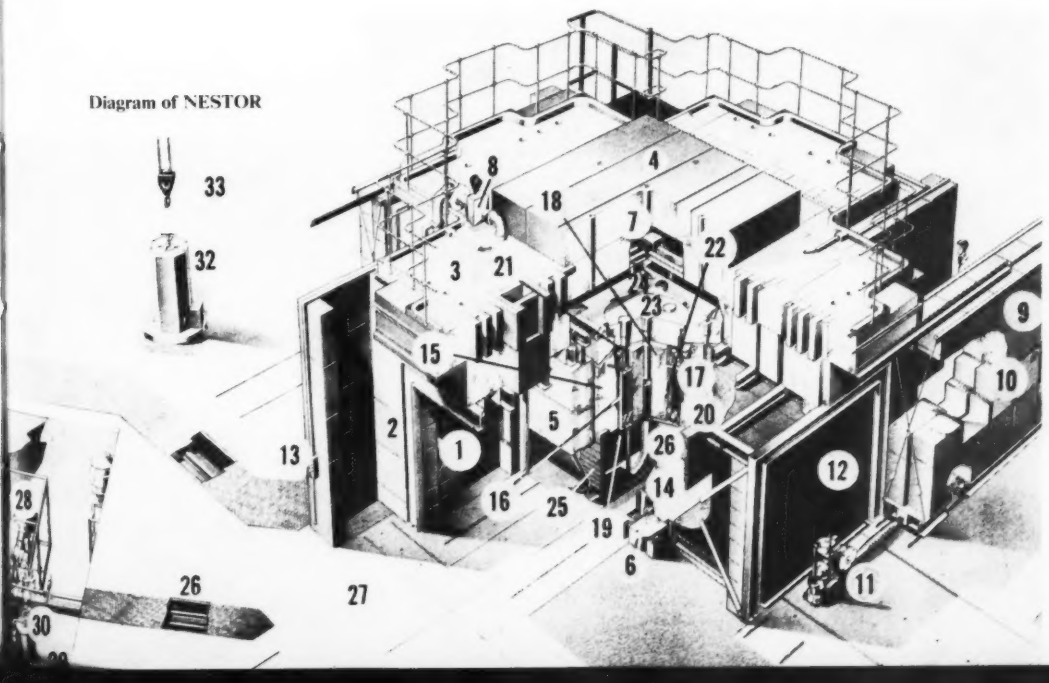
NESTOR itself can operate at 10 kW (heat) to give a thermal neutron flux of 10^{11} neutrons/sq.cm/sec in the centre of the core, and of up to 10^{8} neutrons/sq.cm/sec in the sub-assemblies. Thermal neutron flux for a sub-critical assembly can be varied by altering the power reactor level, by using neutron shutters or by re-arranging the fuel loading in the core.

The reactor core, control gear and instrumentation for NESTOR was designed and installed by the Hawker Siddeley Nuclear Power Company. During the development programme for this contract Hawker Siddeley modified their JASON reactor so that five sub-critical assemblies could be driven simultaneously. This was a major advance in the use of a reactor as a neutron source.

Civil Work

Civil engineering work on NESTOR was carried out by the Turriff Construction Corporation, Ltd. This company was responsible, among other things for the construction of the main biological shielding and the neutron shutters. Most of the shielding consists of precast iron shot concrete blocks each contained in a mild steel frame. Very fine tolerances were specified for this work. △△△

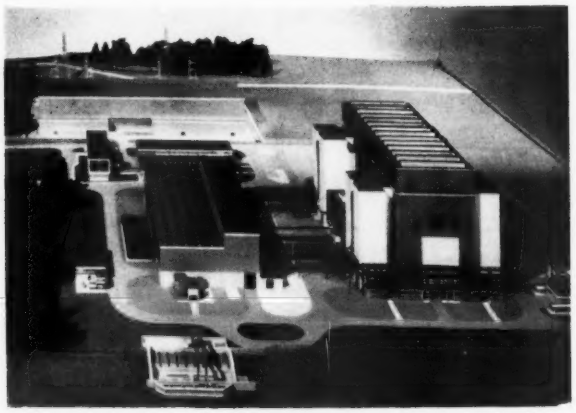
Diagram of NESTOR



Key: 1 Cave structure; 2 Cave wall; 3 Cave roof and access system; 4 Core roof; 5 Neutron shutters; 6 Corner shield pillar; 7 Neutron shutter mechanism; 8 Ventilation fan and filter; 9 Shield doors; 10 Recastable access plug; 11 Door/stack moving mechanism; 12 Graphite stack; 13 Neutron shutter controls; 14 Plinth; 15 Reflector; 16 Reactor outer vessel; 17 Control rods; 18 Central thermal Column; 19 N_2 sparge; 20 Ion chamber; 21 Reactor inner vessel; 22 Fuel box; 23 Rotating plug; 24 Top shield; 25 Lead shield; 26 Dump pipe; 27 Steel floor; 28 Dump tank; 29 Heat exchanger; 30 Ion exchange column; 31 N_2 sparge bottles; 32 Fuel transfer flask; 33 Fuel storage holes.

SIZEWELL

Britain's Compact Nuclear Power Station



This view of the model of Sizewell power station shows the turbine hall on the left with the reactor building flanked by its boilers on the right. In the foreground is the sea water pump house which will provide 25m. gal of sea water/hr for condensing the steam

NOW that work has begun at Sizewell it seems appropriate to give a full description of this power station. The contract awarded to the English Electric-Babcock & Wilcox-Taylor Woodrow Atomic Power Group in November of last year by the CEGB is worth somewhere in the region of £55m. Output capacity will be about 580,000 kW or 780,000 h.p. from two reactors contained in a single building.

The CEGB applied to the Ministry of Power for permission to build Sizewell in January, 1959; this was granted in February, 1960, without a public enquiry. According to present plans the station should be completed and in operation by the end of 1966. By this time the nuclear contribution to Britain's generating capacity will be in the region of 10 per cent. of the total.

Sizewell is situated on the coast of East Anglia about half-way between Ipswich and Lowestoft. Top soil in this region consists mainly of fine to medium sand; the water table is 29 ft below ground level and the substrata which is also sand has good load-bearing characteristics.

Compact

Compactness is the outstanding feature of Sizewell. Unlike previous nuclear power stations built in this country, both the reactors at Sizewell are to be housed in one composite building. In this way considerable savings have been achieved in interconnecting services, the supervisory control room and associated personnel change rooms. In addition, fuelling and reactor servicing machines can be transferred from one pile cap to the other via a maintenance shop. The reactor building and turbine hall are situated parallel to each other and at right-angles to the coast.

Siting of the turbine hall has been arranged to reduce the length of the circulating water culverts from the pumphouse to a minimum. An intake structure, some 1,375 ft offshore is connected to the pumphouse by twin tunnels.

As with the other stations under construction for the CEGB, the reactors will be of the carbon dioxide gas-cooled, graphite-moderated type. The pressure vessel for each will be 63 ft 6 in. in diameter. They will be placed at either end of the reactor building. Four boilers and four main gas circulators will be associated with each reactor. The reactors are to be surrounded by a 5½ ft thick concrete primary biological shield and covered by an 11 ft 9 in. thick roof which will also extend over the area between the reactors. A supplementary shield 5 ft thick will mask the openings in the primary shield for coolant gas and air ducts.

Cranes on the pile cap area will be able to pass over both reactors, thus providing flexibility of operation as a result of which a single central fuel discharge system and one compact cooling pond are sufficient.

Fuel element can design has been improved to give higher heat ratings. The extended surfaces of the magnox can will be of the polyzonal multistart helical thread type which will permit an increased outlet gas temperature. Each fuel channel will contain seven fuel elements, thus reducing fuel costs and improving performance.

Temperature and heat output of the reactors will be controlled by an automatic system. Any major change in heat output will be made by controlling coolant gas mass flow. To do this the setting of the circulator inlet guide vanes and the operation of a gas by-pass system are varied. Gas outlet temperature of the reactors will be controlled by a sector control-rod system and xenon reactivity override obtained by raising inlet gas temperature.

Single stage axial blowers with variable stagger inlet guide vanes will circulate the coolant gas. The blowers, one to each boiler, will be mounted vertically in the base of the boiler and can be easily withdrawn for maintenance.

Pressure Vessel

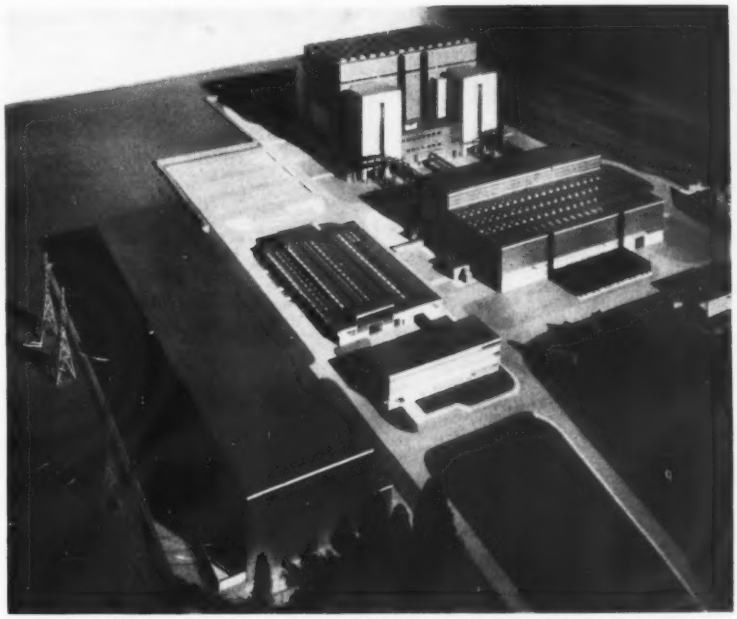
The spherical reactor pressure vessel has 4 in. thick walls and an internal diameter of 63 ft 6 in. Sections will be welded together on site and full use made of the Goliath crane which was first used at Hinkley Point. There will be a cooling cowl on the outer surface and internal insulation of the top of the vessel against hot gas from the core. An angular cruciform section forging transfers the load of the core, which is supported at the vessel bottom by a prefabricated grid, through the vessel envelope. Three hundred penetrations, ranging in size from 6 ft 6 in. internal diameter gas inlet and outlet openings to small sampling and test closures will be made in each vessel.

Some improvements have been made in the design of the CO_2 ducting, but in general the layout has been left as similar as possible to earlier designs.

The boilers have been arranged in pairs on opposite sides of the reactor building. Each is 91 ft 6 in. in overall height and 22 ft 6 in. in diameter. Shells will be fabricated from low-alloy high-tensile steel. Appreciable savings in weight and thickness are achieved by using this steel. Shell sections will be transported by sea to Lowestoft.

Boiler Elements

The boiler elements will be in horizontal banks. Fifty per cent. more steam will be produced by each boiler from a shell only slightly larger than those used at Hinkley Point. Advances in heat exchange surface design account for this increase. Shell penetrations have been reduced to a minimum by the use of trifurcations connecting groups of three elements into a single tube passing through a thermal sleeve in the boiler shell. The by-pass system mentioned earlier for controlling the exit temperature of gas is controlled by a valve system actuated from outside the shell through a displaced bellows positive seal drive.



Model of Sizewell power station showing the indoor switchgear building on the extreme left, the administration block, centre, and the turbine hall on the right in front of the reactor building

While on load it will be possible to operate the boilers from a shielded room in the boiler house basement so that personnel do not have to enter areas of radiation.

Unusual features within the reactor areas at Sizewell will be one reactor building, boiler shielding to eliminate the reactor safety fence, one cooling pond, one central control room, pressure vessel plate thickness over 4 in., which permits higher gas pressure and reduced circulatory power. There will also be common pile cap supervision and change rooms, a common maintenance shop with decontamination facilities, four gas inlet ducts within each pressure vessel support skirt and facilities for easy transfer of pile cap machinery from one reactor to the other.

Cranes working over the pile cap area will be capable of lifting 250 tons on the main hoist and 80 tons on the auxiliary hoist. Accuracy of positioning and control are the main feature of the design. A transfer carriage will be provided to move the fuelling machines from one pile cap to another below the working floor level.

Boxes containing spent fuel elements will be handled over the cooling pond by a Goliath crane travelling on rails at a span of 93 ft 6 in. and having a guided mast with grapple.

The size of the turbine hall has been considerably reduced by using only two turbo-alternators, each rated at a total capacity of 325 MW at a vacuum of 29 in. Hg. The turbines will be mixed pressure machines and will use bled steam to reduce exhaust wetness.

This Goliath crane used at Hinkley Point has been dismantled and is to be transported to Sizewell and used in the construction of the new power station. The bridge is 235 ft above ground level and carries two mechanical grabs each capable of lifting and handling loads up to 400 tons. The crane is shown here under construction at Hinkley Point

The reactor building will be about 400 ft long, 190 ft high and 226 ft wide. The concrete biological shields will be 5 ft 6 in. thick and will form a duodecagon rising to a height of about 96 ft above the foundations. Internal diameter will be about 72 ft.

A concrete raft, 8 ft thick and 225 ft × 110 ft, carries the reactor structure and transmits a load of about 3 ton/sq.ft to the subsoil. The turbine house, which will be about 385 ft long × 155 ft wide, is to be a steel-framed building with electrical and mechanical annexes.

A cooling water intake structure will be provided offshore, through which water will be drawn for the condensers at a rate of over 27m. gal/hr. Excavation of the twin 10 ft diameter tunnels, through which the water will be transported, will be carried out in compressed air. On the outlet side of the condensers, twin culverts are to lead from the turbine house to a deep shaft from the bottom of which twin tunnels will lead to an outfall structure with the point of discharge some 500 ft beyond high water mark.

Over 200,000 cu.yd of concrete will have to be placed to a high degree of accuracy. More than 700,000 cu.yd of material will be excavated mostly in site levelling operations.

By 1966 when the station is due to be completed the labour force will have reached the figure of 2,400 and the site will occupy 24 acres. Considerable transport troubles are expected due to the inadequate roads in the region and for this reason sea transport will be used for the heaviest and most bulky pieces of plant. To meet the expected demand, a heavy lift 200-ton crane is to be installed at Lowestoft Harbour.

At Sizewell great care has been taken to safeguard local amenities. The actual site consists of land with little agricultural value and is sufficiently large to provide for future development. At all stages in the design of this station there has been full consultation with the County Council and the U.D.C.; the Royal Fine Art Commission has commented on the architecture of the proposed buildings.

Sizewell is being built by the CEGB to help supply the base load associated with the rapidly growing demand for electricity in the south-east. The novel features embodied in the design and new techniques have provided considerable economies in the overall cost of the station. As a result of this, power should be generated at a figure well below the national average. △△△

PRINCIPAL DATA FOR SIZEWELL

Station	
Nett electrical output	580 MW
Nett thermal efficiency	30.5 per cent.
Reactors	
Number of reactors/station	2
Reactor heat rating	950 MW
Pressure vessel diameter	63 ft 6 in.
Pressure vessel thickness	Over 4 in.
Coolant	CO_2
Reactor inlet pressure	279 lb/sq.in. absolute
Fuel	Natural uranium
Fuel rod diameter	1.1 in.
Fuel charge/reactor	321 tonnes
Mean fuel heat rating	2.95 MW (heat)/tonne
Number of elements per channel	7
Boilers and Turbines	
Number of boilers	8
H.P. drum pressure	720 lb/sq.in. absolute
H.P. superheater outlet temperature	391 C.
L.P. drum pressure	305 lb/sq.in. absolute
L.P. superheater outlet temperature	390 C.
Steam pressure at H.P. boiler stop valve	677 lb/sq.in. gauge
Steam temperature at H.P. boiler stop valve	389 C.
Steam pressure at L.P. boiler stop valve	268 lb/sq.in. gauge
Steam temperature at L.P. boiler stop valve	389 C.
Vacuum	29 in. Hg
H.P. steam flow from each boiler	5.4×10^5 lb/hr
L.P. steam flow from each boiler	1.9×10^5 lb/hr
Boiler dimensions	91 ft 6 in. × 22 ft 6 in.
Number of main turbines	2
Output of each turbine	324.75 MW
Main Circulators	
Number of circulators	8
Type of circulators	Vertical, single stage axial with variable stagger inlet guide vanes
Drive	Vertical squirrel cage induction type motor
Civil Engineering Data	
Height of reactor building	193 ft
Length of reactor building	400 ft approximately
Mean thickness of concrete main shield	5 ft 6 in.
Mean thickness of concrete supplementary shield	5 ft
Distance across flats of main shield	72 ft 3 in.
Height of concrete main shield	86 ft 2 in.
Thickness of pile cap	11 ft 9 in.
Foundation of reactor building	Reinforced concrete raft 225 ft × 110 ft × 8 ft thick
Turbine hall overall dimensions	Approximately 385 ft × 155 ft wide × 94 ft high
Pumphouse dimensions	125 ft wide × 133 ft long

AERE MONOGRAPHS RECEIVED

Pinch Collapse, by K. Hain. Published by Theoretical Physics Division, AERE, Harwell. Reference AERE-R3383. Available from HM Stationery Office. Price 5*s*.

A Device for the Synchronisation of Two Dropping Mercury Electrodes, by W. H. Lockwood. Published by Chemistry Division, AERE, Harwell. Reference AERE-R3521. Available from HM Stationery Office. Price 1*s*. 9*d*.

Gas Gain Drift in a Gas Flow X-ray Proportional Counter; a Method of Stabilisation, by C. E. Mellish and J. A. Payne. Published by Isotope Research Division, AERE, Harwell. Reference AERE-M794.

District Gamma Radiation Survey Around AERE, Harwell: Results for 1958 and 1959, by A. Morgan. Published by Health Physics Division, AERE, Harwell. Reference AERE-M761. Available from HM Stationery Office. Price 1*s*. 9*d*. △△△

Critical Experiment for HTRE - III

by Bruce W. Link
and Richard G. Clark

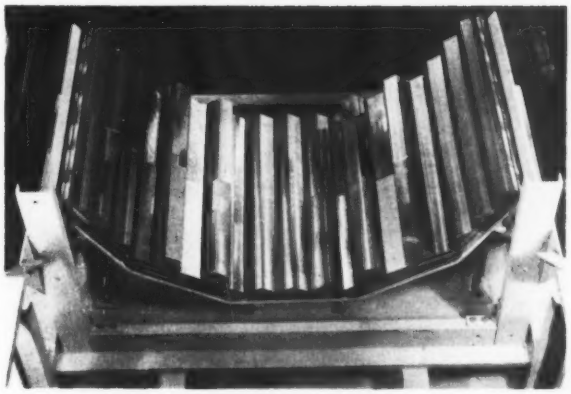


Fig. 1.—Tubular solid moderator radial reflector, lower half

THE design and fabrication of the HTRE-III reactor represented an intermediate step in the ultimate production of a direct air cycle reactor for nuclear propulsion of military aircraft. Existing analytical techniques for reactor design did not readily lend themselves to the geometrical complexity inherent in this type of reactor. The need for experimental verification of these techniques was obvious. To this end, a critical experiment was designed and built, incorporating the best nuclear, mechanical, and thermodynamic specifications available from applied theory. The result was the TSM (Tubular Solid Moderator) critical experiment, a physical and nuclear mock-up of the HTRE-III reactor.

Basic specifications for the design of the HTRE-III reactor included: (*a*) constant hydraulic diameter fuel elements: (*b*) incorporation of solid moderator, namely hydrided zirconium, clad in order to minimize hydrogen migration and loss: (*c*) radial power flattening accomplished by varying hydrogen density (N_H) in the moderator: (*d*) relatively thin radial reflector, augmented by a water shield, and (*e*) cooling of moderator, reflector and control rods with primary air.

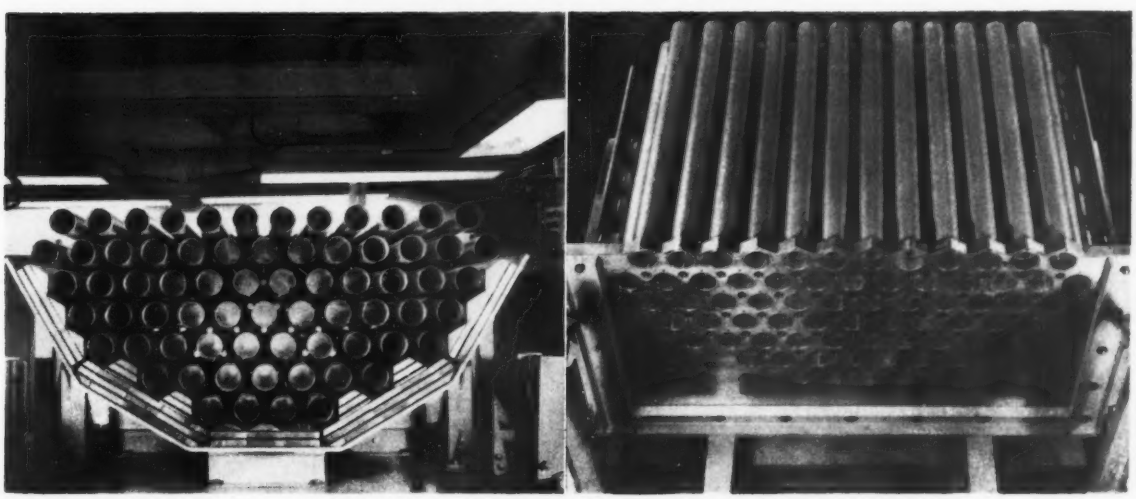
Control System

The TSM control system consisted of five absorber rods, lead-screw actuated with a positioning accuracy of ± 0.01 in. The safety system consisted of 10 rods, air-cocked, magnetically held, and spring-fired, with a drop time of no more than 200 millisec. The rods consisted of boron carbide sections, 30 in. long, and approximately 0.65 in. in diameter. The boron carbide rods, which were used exclusively in the critical experiment, simulated europium oxide absorber rods specified for the design reactor.

Figs. 1-5 show various assembly stages of the critical experiment. Fig. 1 shows the radial reflector in one half of the assembly. The air gaps, which are visible between the beryllium slabs, represent a specific void volume necessary for reflector cooling. The design pressure shell was simulated with $\frac{1}{2}$ in. thick mild steel. Fig. 2 shows front and rear views of the lower half of the assembly, consisting of the radial reflector and the forward tube sheet, into which stainless steel tubes were swaged.

These tubes served a dual purpose. Primarily, they contained and positioned the fuel elements, and as a

Fig. 2.—Tubular solid moderator assembly, lower half



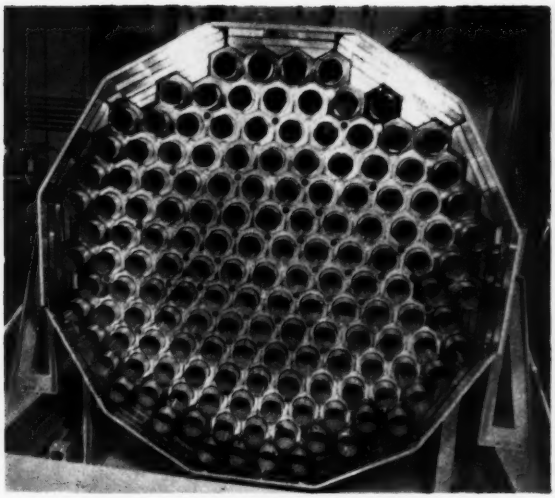


Fig. 3.—Tubular solid moderator assembly, upper and lower halves joined

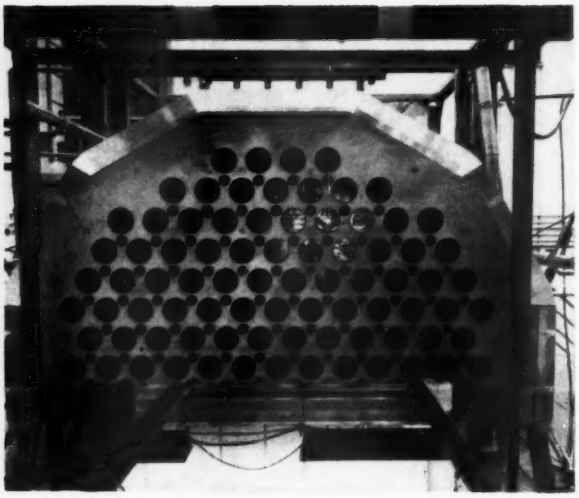


Fig. 4.—Tubular solid moderator assembly, upper half

secondary function, they simulated the cladding for the inner surfaces of the moderator pieces. Fig. 3 shows the nearly completed assembly, with the exception of two moderator pieces, the aft tube sheet, and the fuel elements. It can be noted that, with few exceptions, the alternate corners of all the hex-shaped moderator pieces were milled out, resulting in longitudinal voids throughout the core.

The flexibility of the assembly was considerably increased in that either moderator bars or poison rods could be manually placed in these voids, resulting in a variety of configurations. In this particular photograph the poison rod positions, which are shown as voids, represent the pattern specified for the design reactor. Moderator cladding material was simulated with appropriate thicknesses of stainless steel placed adjacent to all longitudinal surfaces of the moderator pieces.

Each moderator hex was independently cantilevered from the forward tube sheet. In addition to the mock-up cladding material, a small void area existed around all moderator surfaces in order to provide a physical approximation of moderator cooling passages.

Fig. 4 shows the upper half of the core with the aft tube sheet in place. A mock-up of a water shield consisting of 4 in. of acrylic plastic is visible, radially outside the pressure shell. Fig. 5 presents an end view of the upper half of a typical TSM core with fuel elements and poison rods in place.

Hydrogen density

As was mentioned before, gross radial power flattening was to be accomplished by varying the hydrogen density of the moderator material, hereafter referred to as N_H. In order to present a base point for comparison purposes, ordinary water contains roughly 6.5×10^{22} atoms of hydrogen/cc, or has an N_H of 6.5. Fig. 6 presents a schematic view of the TSM assembly cross-section. The N_H generally increased from the centre of the core outward. In (*a*), which was the pattern originally specified for the critical experiment, the three indicated regions represented values of 2.5, 3.0 and 3.95. In (*b*), which

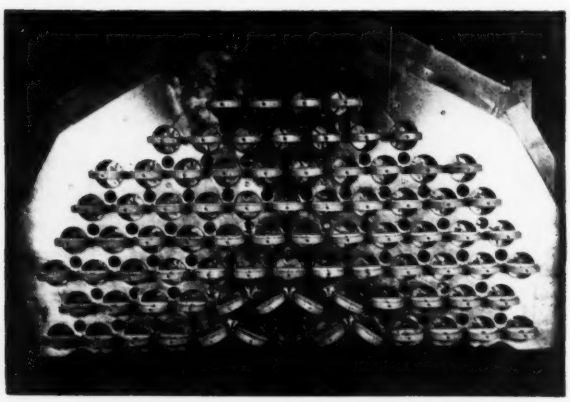


Fig. 5.—Completed tubular solid moderator assembly, upper half

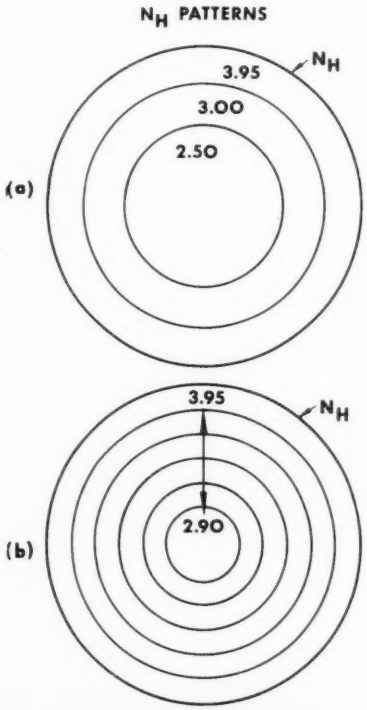


Fig. 6.—Tubular solid moderator hydrogen density (N_H)

indicated later trends in N_H pattern definition, the N_H varied from 2.90 to 3.95 in six discrete steps. The final hydrogen density pattern utilized in the HTRE-III reactor was even more complex than indicated. Local problems from a thermodynamic standpoint were minimized by readjusting the N_H of specific fuel element moderator pieces, thereby breaking up the "complete ring" pattern in some instances.

Density pattern

In the process of changing the hydrogen density pattern from the original three N_H regions to a more usable pattern which included six different N_H values ranging from 2.90 to 3.95, the existing hex-shaped moderator pieces were re-worked as follows:—

(i) Major changes in N_H were accomplished by out-gassing the appropriate pieces and re-hydriding to the specified value.

(ii) Small changes in N_H were obtained by enlarging the bore diameters of the hexes, thereby removing hydrogen. The resultant reduction in zirconium volume was considered to have a negligible nuclear effect.

The basic specifications from which the TSM assembly was designed are given in Table I.

Specifications

The core volume fractions shown here represent preliminary specifications set for the design reactor. These specifications were used as a target in the design and fabrication of the critical experiment and are fairly representative of the actual critical experiment specifications. It must be borne in mind that the overall critical experiment programme, and consequently, the prototype reactor design programme, continued for nearly two years, encompassing a great deal of experimental and analytical iteration. It will suffice to say that the specifications indicated here were continually dependent on these iterations and, during a large part of this time, remained flexible.

One of the more unique features involved in the design of the TSM was the extent of material substitution and geometrical approximations which went into its design. For example, the difficulty in machining high-nickel steel alloy prohibited its use in the critical experiment because of the imposed time schedule; therefore, stainless steel was substituted in the main structural components of the core and in the control rod guide tubes. Sheet molybdenum was not readily available; hence, stainless steel was used to simulate moderator cladding instead of molybdenum. Since ordinary water and acrylic plastic are not too dissimilar from a nuclear standpoint, the plastic was a logical choice to replace a water shield.

Composite result

The utilization of these various mock-up techniques came about as the composite result of analytically matching nuclear cross-sections of design and mock-up materials, some experimental measurements, and a rigorous application of the black art of nuclear intuition, or, in other words, "seat-of-the-pants" nuclear engineering. From after-the-fact comparisons of critical experiment measurements and nuclear data obtained from the design reactor, the composite effect of all of these material substitutions and geometry approximations was that of increased confidence in the techniques.

In the course of two years of operation, we studied nine different core configurations. Some of these represented close mock-ups of the HTRE-III reactor while others were experimental design iterations. In the remainder of the paper, we will relate the sequence of TSM configurations to the evolution of the final HTRE-III reactor design. While the importance of power measurements is understood, the major emphasis will be given to the reactivity effects as a basis for comparing the various cores.

After the TSM went critical, its first use was in the selection of a satisfactory operating mode for the shim and dynamic rods in the power reactor. Should they be withdrawn during start-up in some radial sequence or should they be ganged together and move as one rod? The three cores obtained to answer this question will be described with reference to their poison rod radial importance functions as presented in Fig. 7.

The first configuration approximated operation of the HTRE-III with the peripheral rods withdrawn.

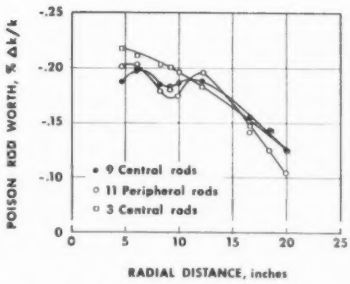


Fig. 7.—Tubular solid moderator boron and rod radial importance function

Nine central rods were left fully inserted (20 in.) in the TSM at about 5 in. radially from the centre of the core.

Operation with the most central rods withdrawn was simulated in the second core which contained 11 rods remaining fully inserted at about 17 in. radially. For the third core, the k_{ex} of the assembly was reduced by inserting thin cadmium wires uniformly throughout the core. This manipulation allowed the withdrawal of all but the three innermost rods, at about 4½ in. radially. The effects of these three configurations are seen in Fig. 7. The most important effect of these changes was not in reactivity, however, but in power perturbations. Power mappings indicated that the least serious power perturbations

Table I.—Specifications Used as a Basis for Critical Experiment Design in Heat Transfer Reactor Experiment III

Overall core length	35.5 in.
Length of fuelled section	30.5 in.
Length of poison segments	20 in.
Effective diameter of core, minus reflector	51.8 in.
Moderator material	Hydrided zirconium
Fuel inventory	Approx. 365 lb of U-235
Primary heat transfer material	Nickel-chromium alloy
Moderator cladding	Molybdenum
Control rod cladding	Stainless steel
Structural material	High-nickel steel alloy

VOLUME FRACTIONS

Active core, excluding tube sheets, reflector and control rods

Material	*Volume fractions*
UO_2	0.017
Nickel-chromium alloy	0.076
Stainless steel	0.025
Molybdenum	0.025
Zirconium	0.401
Structural material	0.004
Void	0.452

would exist if the rods were moved simultaneously as one bank of rods.

Comparison

A comparison was made of the TSM and prototype fuel elements in the first core, with nine central rods. In Fig. 8, the radial importance functions are seen to be of the same character, with the prototype element averaging slightly more valuable, about 6 per cent. The TSM elements did not include hardware used to position and latch the design elements in the HTRE-III. Coils of steel were put through the forward and aft tube sheets to approximate these pieces. This change, and others, made the TSM elements more valid mock-ups and reduced the reactivity discrepancy to about 4 per cent.

Based partly on the reactivity results and power mappings of the first three cores, certain design modifications were proposed. The next series of configurations was aimed at experimentally observing the results of some of these changes and at improving the mock-up validity of the critical experiment.

For example, the central zirconium hex was hydrided in the early cores. This hex was removed and one containing no hydrogen was inserted. Materials simulating the central structural support for the core were inserted into the central " dead " moderator hex.

Barrier

The original HTRE-III specifications included moderator cladding to act as a high temperature diffusion barrier for the hydrogen. Early reactivity tests had shown that the design cladding would be a significant poison to the core. Independently, basic research aimed at a suitable moderator-clad bonding had not proven fruitful at this particular time. These two problems led to a decision to over-cool the moderator, thus eliminating the very need for a high temperature cladding.

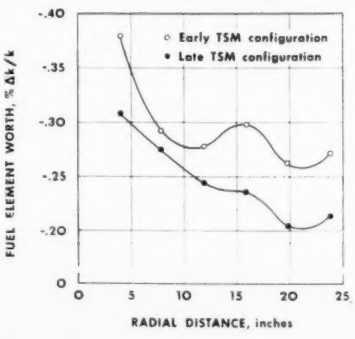
The core was first changed by removing materials simulating the moderator cladding. Longitudinal cooling slots along the bore of the moderator hexes would effect about a 5 per cent. reduction in the moderator volume fraction. An indication of the reactivity change due to moderator removal was gained when all 80 manual moderator bars were removed from the TSM. For another core change, stainless steel mock-ups of design fuel element insulation liners were inserted around each element. The liners were designed to separate and insulate the relatively low temperature air cooling the moderator from the hot fuel element air.

By this time, the gross design specifications of the HTRE-III reactor had been set and hardware had begun to appear. The TSM was then modified to these specifications. The moderator hexes were removed and rehydrided to the final moderator distribution. The total core hydrogen loading went up about 5 per cent., with most of the additional being made to the central regions of the core to obtain the desired gross radial power shape. While the total hydrogen content went up, the moderator volume fraction decreased by about 5 per cent., simulating the inclusion of the moderator cooling slots. The total core fuel inventory was increased by about 5 per cent. to achieve the design k_{ex}.

For the last configuration, thin cadmium wires were again inserted uniformly throughout the reactor to reduce the k_{ex}. In accordance with the operating mode previously established, the entire bank of TSM poison rods was withdrawn to an insertion depth of 10 in. into the core. This particular position of the rod bank was of no special significance, except that it represented the rod insertion at some time during the operation of the HTRE-III.

The longitudinal power shift due to the poison withdrawal was the important effect studied in these two cores. However, since they were built to the final gross specifications of the HTRE-III, these last two configurations also provided last-minute

Fig. 8.—Tubular solid moderator fuel element radial importance function



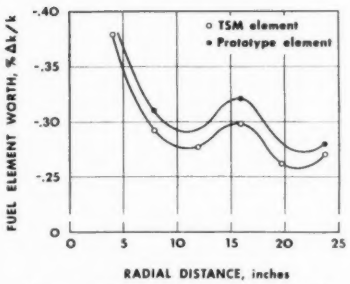


Fig. 9.—Tubular solid moderator fuel element radial importance function

checks of the design calculations before the power reactor went critical. This information was useful, for instance, in that a few localized potential "hot spots" were identified within the core. To deaden these " hot spots," small strips of high boron steel were included in the HTRE-III insulation liners as they were assembled in Idaho.

Configurations

Fig. 9 illustrates the fuel element importance functions of the first and one of the last TSM configurations. These two cores are not necessarily simulating the same condition. The comparison is made, however, to indicate the accumulative effects of some of the gross changes of the assembly. In the interim between these two configurations the fuel and hydrogen inventories were increased, but the moderator volume fraction was decreased. Moderator cladding mock-ups were removed, but simulated fuel element insulation liners were inserted. These changes effected a net decrease in the average fuel element worth. The later core also contained a " dead " central moderator hex. The general tipping of the later curve has been attributed to the fact that, in the addition of hydrogen, the greatest change was made in the central core regions.

We were able to make a brief reactivity evaluation of the design radial shield tank. The acrylic plastic normally located beyond the TSM pressure shell mock-up was to simulate the water shielding within the tank. Steel and lead slabs were placed outside the upper flat of plastic to approximate other shield materials. Test results indicated that the design shield, without water (or " dry ") should contribute positive reactivity to the reactor; that adding water should decrease the positive worth of the shield, and that

materials located beyond water in the "wet" shield should be of little worth. These results were consistent with those obtained in Idaho on the design reactor.

Finally, we would like to say just a word about how we measured reactivity. Our basic approach to reactivity was not novel. For several control rods, we determined and plotted the relative integral worth as a function of the insertion into the core. From this curve, we could associate a certain fraction of the worth of a given rod with a particular asymptotic reactor period. By solving the reactivity equation with the appropriate constants, we related this period to a worth, expressed in percentage $\Delta k/k$. Thus, each control rod was calibrated. All other reactivity measurements were comparisons of the critical control rod settings for various core conditions.

After the control system had been calibrated, we usually proceeded to find the total reactivity associated with the assembly. Instead of testing each manual rod, we made use of the six-fold symmetry of the core and measured only "typical" manual rods. The worth of each typical rod was multiplied by the number of identically positioned rods it represented. What we called "assembly reactivity" was defined as the summation of the worths of all poison rods in the core at critical. Because of the high degree of poisoning of the reactor, this worth could only be an approximation of the effective excess multiplication of the system. △

This paper was presented to the American Nuclear Society on December 13th, 1960.

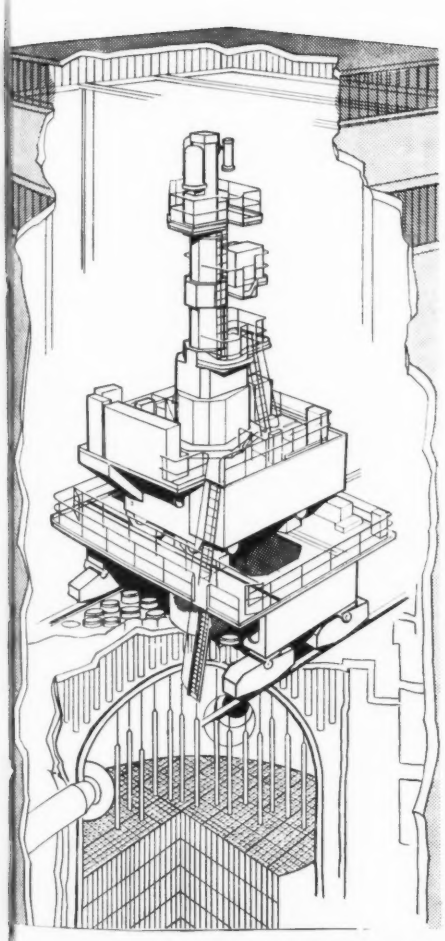


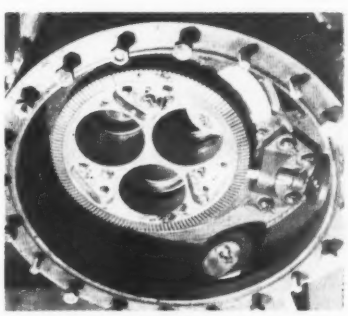
Diagram of refuelling machine mounted on the AGR

Refuelling Machine for the A.G.R.

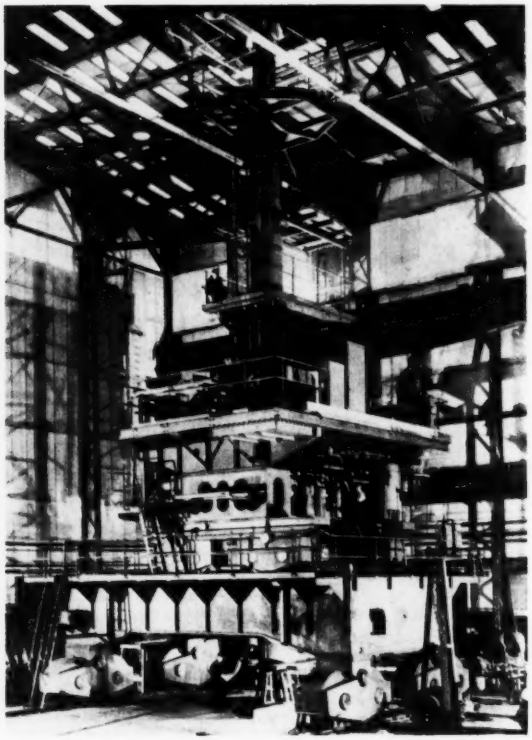
EXTREME accuracy is the keynote of the refuelling machine for the AGR now nearing completion at the Chesterfield works of Markham, Ltd. Work on this machine started well over two years ago with a design put forward by John Brown (SEND), Ltd., an associate company of Markhams. At that time a positioning accuracy of ± 0.005 in. was anticipated, but with the machine now virtually completed the engineers are prepared to guarantee an accuracy of ± 0.002 in.; no mean achievement when moving a piece of machinery weighing over 400 tons and more than 60 ft high.

With the AGR a single fuel element is far more important than in the Calder Hall type reactor, and for this reason when in operation the refuelling machine must be treated as a part of the control system. This has meant the expenditure of a sum well in excess of £250,000, the solution of many difficult research problems and the development of a unique servo system which is at present the subject of patent applications.

Replacement of fuel elements will be accomplished while the reactor is under full load and pressure. Two pressure handling vessels are used in the operation, the first under normal conditions and the second in the event of a fuel element being damaged or broken. The normal vessel, 2 ft in diameter and 56 ft long, consists of a rotary magazine with three compartments, one for the used element, one for the new element and the last for a stand-by reactor seal plug.



Magazine rotating assembly for special handling facility



The refuelling machine in course of assembly at the Chesterfield works of Markham & Co. Ltd.

Both these vessels are mounted vertically on a superstructure consisting of a crab and gantry. In this way all 253 reactor refuelling branch pipes can be covered. In the refuelling operation a manual connection is first established between the machine and the fuel plug string. The machine is positioned manually to within ¼ in., when the servo system takes over. A nose is extended from the handling vessel to connect with the selected refuelling branch and a pressure-tight seal is effected between the machine and the reactor. A sensing device in the nose controls fine positioning of the machine.

These operations take place in a strict sequence and each operation has to be "cleared" before the next one begins. Special electrical and mechanical equipment is used to facilitate positioning, this includes closed-circuit television by which the operator can watch the entire sequence inside the handling vessel.

Cooling System

When positioning is complete the spent plug string is hoisted into the magazine, which is rotated and the new one lowered and locked into the reactor. During hoisting of the spent element the machine's cooling system takes over from that of the reactor to ensure continuous cooling until disposal. The cooling system and the handling vessel both have a design pressure of 500 lb/sq.in.; the design temperature is usually 325°C. rising to 400°C. in places. Shielding of both vessels is provided by 22 in. of cast iron for protection against gamma rays and 9 in. of laminated wood for fast neutron shielding.

When completed, the machine will be dismantled, a task taking six weeks, and transported to Windscale. Reassembly on top of the AGR will take about four months and should be completed in October this year. △

Trade Literature received

Peabody, Ltd., have produced a new Bulletin, No. LH203-D, giving details of their improved Gas Scrubber, which is now fitted with an agglomerating slot stage. The applications of the scrubbers are described and illustrated with diagrams and photographs, together with brief technical details.

To meet the specifications laid down by the UKAEA and manufacturers of electrical components much research has been devoted to the development of new base films and adhesives for the electrical industry. The latest Sellomation Picket Information Booklet, Electrical Taping, describes the properties of a number of these tapes. Information on their physical and electrical properties is provided, enabling a prospective user to select the correct taping medium for his particular application. This range of tapes can be used in component production or maintenance work around factories. Among problems referred to are corrosion by alkali and acid penetration, high temperature work, and phasing and circuit identification. Applications of interest to component manufacturers and maintenance engineers are dealt with and in each case a method and tape is suggested.

The latest publication from EMI Electronics, Ltd., is a Nuclear Health Short Form Catalogue, which gives specifications for the company's wide range of monitors and probes for use in laboratories and other establishments where radioactive materials are handled. All the instruments are illustrated. Details are given of the company's hand and clothing monitor, which will process three people simultaneously and also the single-hand monitor designed for smaller establishments requiring an inexpensive instrument. Other equipment described includes a low activity sample monitor which incorporates its own lead castle and end window Geiger counter to form a portable counting system—and a portable contamination monitor for checking such surfaces as benches.

As an addition to electronic engineers' files of reference material a short form catalogue has been published by EMI Electronics, Ltd.'s Instrument Division. This well illustrated booklet covers all the Division's products from colour television cameras to electronic photographic equipment, analogue computers and health monitors. Details are given of the company's wide range of industrial stroboscopes, oscilloscopes, instrumentation tape decks and multitrack heads, together with their black-and-white closed circuit television equipment and many different remote-control units and accessories. △△

THE INSTITUTION OF NUCLEAR ENGINEERS

SECOND PAPER

Professor Joklik presents his Paper at last month's Institution meeting

(*Above*) Dr. Wehrli and Professor Joklik demonstrating the oxygen-UV apparatus

(*Below*) The informal discussion. Professor Joklik is on the extreme left, behind the Vice-President, Mr. D. S. Watt

The second Institution Paper was presented to a meeting of the Institution at the Junior Institution of Engineers in London on April 18th. Professor Joklik of Italy presented the Paper, which consisted of two parts; the first part dealt with the radiation polymerization of methyl methacrylate and included a description of an industrial scale plant at present being built at Palermo in Italy under the direction of Professor Joklik. The second part of the paper dealt with a new gamma convergency cancer treatment and a special oxygen-UV blood treatment for catalase activation. In presenting part two of the Paper, Professor Joklik was assisted by a practical demonstration by Dr. Wehrli of Switzerland. Part one of the Paper is presented below and part two will appear in the June issue.

Radiation Polymerization of Methyl Methacrylate

by Otto F. Joklik

THE production of polymerized methyl methacrylate and other allied polymers shows a constant upward trend which has by no means reached its highest point as the quick development of the synthetic materials industry and its still rising production curve proves beyond any doubt.

Plates made from polymerized methyl methacrylate are a very valuable and useful synthetic material which have been used for quite a number of years in many branches of industry and commerce (engineering, publicity, applied arts and crafts, etc.). It is polymerized from monomeric material and converted to plates, blocks and other special shapes in a special polymerization process. The monomer itself is made from acetoncyanhydrine, methanol and sulphuric acid.

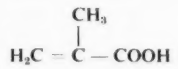
There are only a few manufacturers and supply is far from meeting the demand which continues to increase and a particularly promising market is opening up. The smallest economic plant must have a monthly output of about 25 tons. The plant described in this article is geared for a monthly output of 50 tons of finished product. Contrary to all other manufacturing processes utilizing

chemical catalysts such as benzoyl peroxide and butyronitriles, etc., and considerable thermal treatment of the monomer during the prepolymerization stage, the process in question utilizes high energy gamma radiation from a multikilocurie Co60 gamma source for polymerization initiation.

Acrylic Acid

Acrylic acid $CH_2-CN-COOH$ is an unsaturated organic compound which can be easily polymerized. Under practical production conditions some derivatives of the acrylic acid are used; for example, acrylonitrile is required in considerable quantities for making poly-acrylonitrile (spun Orlon fibre) or for the manufacture of BUNAN, also some esters (*e.g.*, methyl-, ethyl- and butyl-ester, etc.) are used for making safety glass or for being co-polymerized with methacrylates.

The methacrylate resins in question have to be derived from a higher homologue of the acrylic acid, *i.e.*, from alpha-methacrylic acid:



which is commonly called methacrylic acid.

Methacrylic acid and its ester and nitrile are colourless in the pure state and can be polymerized easily under

Table I.—Manufacturing Process for Methyl Methacrylate Polymer

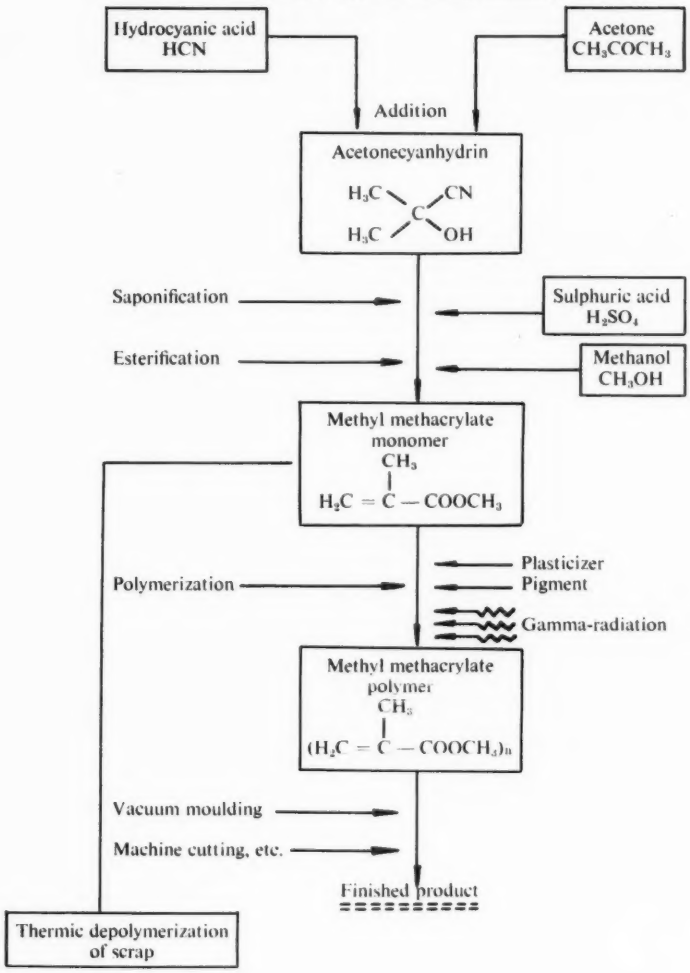
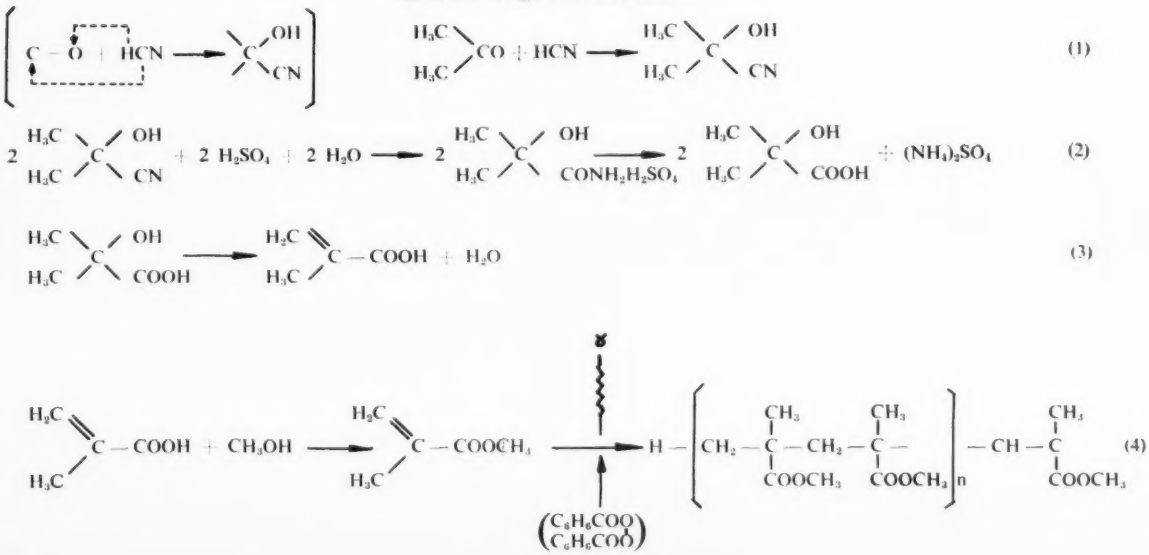
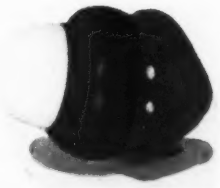


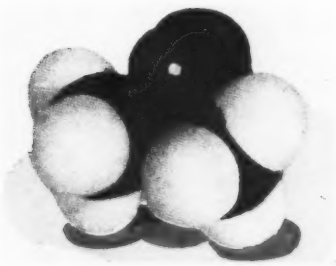
Table II.—Diagram of the Reaction



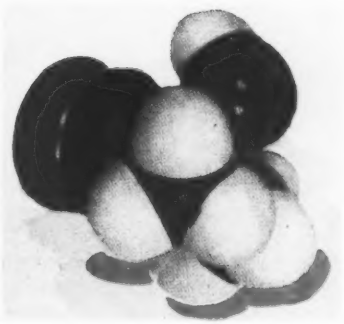
The models shown on this page and the following one represent various combinations in Tables I and II

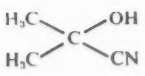


HCN (hydrocyanic acid)

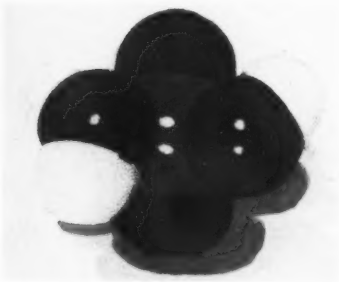


CH_3COCH_3 (acetone)

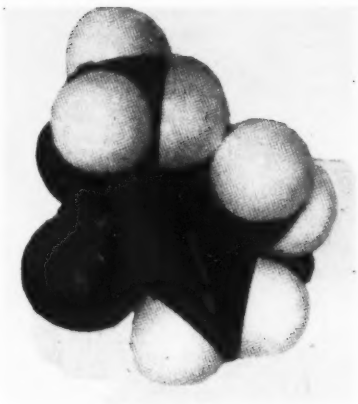


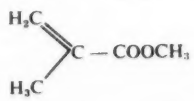


(acetonecyanhydrine)



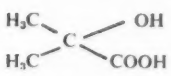
H_2SO_4 (sulphuric acid)



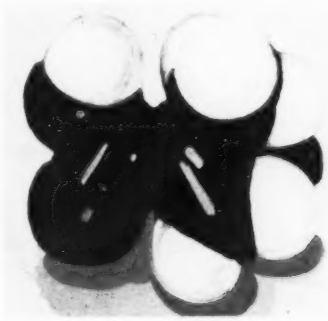


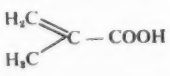
(methyl methacrylate monomer)

CH_3OH (methanol)

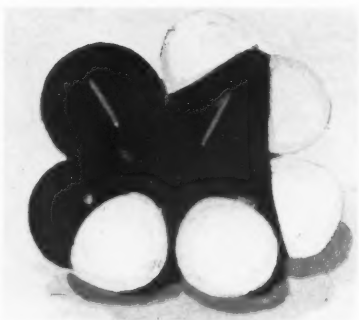


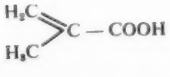
(intermediate product)



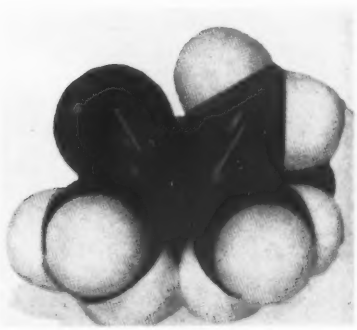


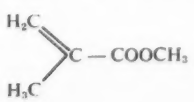
(methacrylic acid)





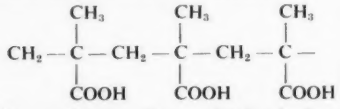
(methacrylic acid)



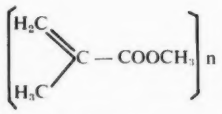


(methyl methacrylate monomer)

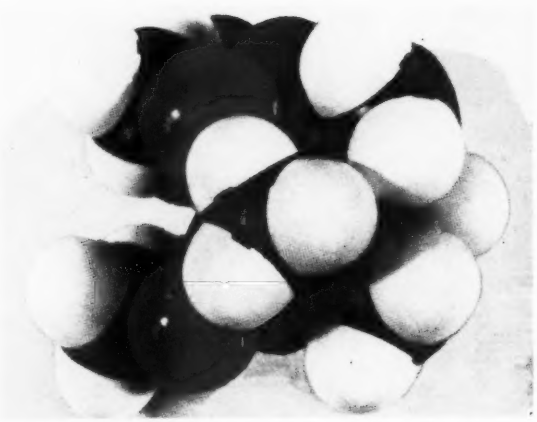
the influence of light, heat, and oxidizing agents so that chains of the following structure are formed:

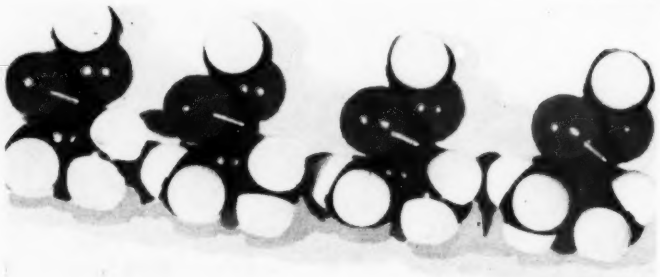


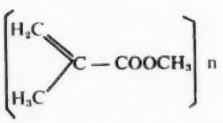
The polymer thus obtained has chemical and physical characteristics which differ widely from those of the monomeric product. Generally, monomers are liquid, volatile and have a low boiling point, apart from being easily saponifiable with alkaline substances, etc. In contrast to this, high polymers are available as a



(methyl methacrylate polymer)



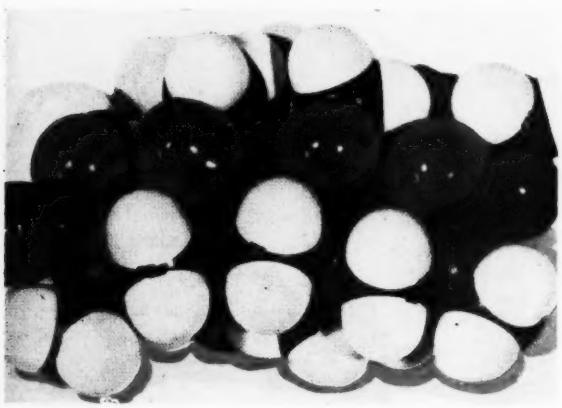


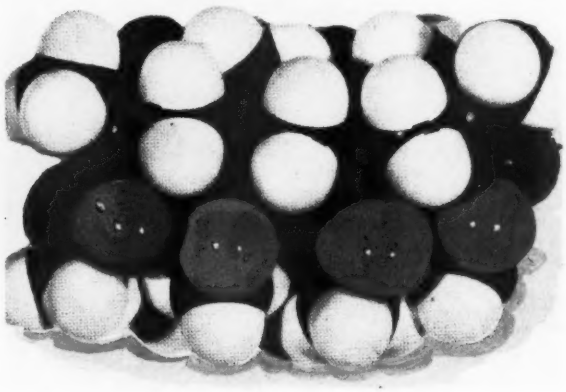


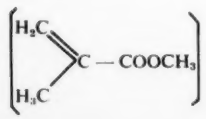
(methyl methacrylate polymer)

solid product having a high consistency which ranges from glass to rubber. They are plastifying at temperatures below that of decomposition and they are decomposed above the latter to be converted into monomers and some other decomposition products, a process known as thermal cracking of the polymer to yield monomer. Another feature of methacrylate resins but mainly of its esters is perfect stability against light, acids and bases of mean concentration.

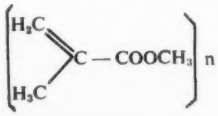
The highly attractive properties of this material, *i.e.*, its absolute colourlessness, transparency, brightness, resistance to light, considerable resistance to chemical influences, low water absorption, very high dielectrical coefficient, easy thermoplastic and mechanical processing, relatively low weight, etc., make it particularly interesting for large-scale production. The large-scale polymerization plant is subdivided into the following processing stages in which the monomer is poured, after radiation polymerization initiation, into so-called sandwich moulds made of glass-plates; after weighing, it is polymerized in furnaces according to a specific processing schedule: (1) preparation of the glass-plate moulds; (2) preparation of the mixture (monomer, plasticizer, pigments); (3) prepolymerization (radiation initiation of the polymerization); (4) pouring of the prepolymerized mixture into the glass-plate moulds; (5) polymerization in a furnace or water bath; (6) stripping of polymer plates from the moulds; (7) inspection, packing,







(methyl methacrylate polymer)



(methyl methacrylate polymer)

paper coating and cutting to shape of the polymer plates; (8) storage of the final product (polymer plates); (9) washing and drying of glass-plates for moulds; (10) distillation of the monomer to remove stabilizer; (11) thermal decomposition (cracking) of polymer scrap to monomer; (12) laboratory, quality control and weighing section.

The methyl methacrylate monomer is polymerized isothermically, a process in which its volume is considerably reduced. This reduction may go as far as 25 per cent., and results from the difference in density (specific weight) between the monomer of 0.93 and the polymer of 1.18.

Heat Conductivity

In addition to the heat development and the volumetric contraction, the low heat conductivity of the polymer is another characteristic. All difficulties which may arise during the polymerization process are due to any or all of the aforementioned characteristics. The monomer is polymerized in so-called sandwich-moulds. These consist of previously prepared plates made of mirror glass and polymerization is carried out at the required temperature in a special furnace, designed as a large drying cabinet or a water bath in suitable hot-water containers. As already mentioned, the sandwich-moulds for polymerizing the monomer are made of mirror-glass plates kept together by adhesive paper tapes. This makes the moulds flexible and they can adapt themselves easily to the material contracting under polymerization.

The mixture to be polymerized is prepared to certain specifications and in containers designed for this purpose. Composition, quality and colour depend on the polymer plates to be produced.

When prepared the mixture is prepolymerized by high energy gamma radiation originating from a multi-kilocurie Co60 gamma source in a particular lead-shielded irradiator before being poured into the preheated glass-plate moulds. The moulds are then closed with adhesive impermeable paper tape and either placed horizontally in the polymerization furnaces by means of a rolling grating or rack or in certain cases placed vertically in a hot-water bath. The amount is not determined by volume but by weight of the specific quantity required in each process.

When the polymerizing product in the furnace has reached a specific state the glass-plates of the mould are separated by a special device so that the stock may fully and freely contract without being impaired. After that the process is continued according to the predetermined polymerization programme.

After the polymerization the moulds with the polymerized plates between the glass-plates are lowered into a water bath to facilitate stripping of the finished polymer plates, whereupon the glass-plates are washed as mentioned above.

Defects

Finished polymer plates are inspected on a table for faults and thickness is checked at the same time. Defects found are marked with a special pencil so that smaller defects may be eliminated by cutting the plates to a smaller size. After the inspection the polymer plate is protected by a paper layer pasted on with fish glue. This paper protects the plates during transportation and also leaves a smooth, bright surface on removal by the customer.

The plates are finally cut to the required size before being passed under an alpha-ray emitter to eliminate static electricity before storage. Waste from the cutting process, etc., is passed on for thermal decomposition (cracking) to depolymerize to monomer.

Thus the production process of polymer plates is completed. They are used in further thermoplastic processes, vacuum-moulding, and in machine cutting, etc., in various processing industries.

For the production of methyl methacrylate polymer in the process in question, the following sizes and thicknesses are used at present:—

Thickness	*Size*
3–6 mm	1,000 × 1,200 mm
	1,600 × 1,000 mm
	1,300 × 900 mm
	1,200 × 900 mm
2–12 mm	1,600 × 1,000 mm
1.5–30 mm	1,200 × 900 mm
	1,300 × 900 mm

Other sizes and thicknesses may be made according to requirements and market demands.

The polymerization furnaces and other plant items are designed for the production of polymer plates up to a maximum size of 1,600 × 2,000 mm (finished plate) and thicknesses up to 30 mm.

Table III.—List of Operations Carried Out in the Manufacture of Polymer Plates of Methyl Methacrylate

Section I

Checking of new glass plates.
Storage of glass plates.
Park for transportation trolleys.
Softening of remnant paper tape on used glass plates (after separation).
Washing of glass plates with hot water.
Polishing of glass plates with red iron-oxide.
Washing of glass plates with fresh tap water.
Washing of glass plates with distilled water.
Drying of glass plates in drying furnace.
Preparation of moulds (tables with pegs, table with adhesive tapes, rack for storing sticks).
Drying of moulds in furnace.

Section II

Storage facility for monomer (tank of 3 cu.m capacity with cooling jacket (5-10 C.) and flow meter).
Distillation of stabilized monomer.
Mixing and preparation of mixture (weighing facility and various mixers for colours).
Filtration of mixture.
Radiation prepolymerization.
Polymerization in furnace.
After-polymerization of certain qualities in water bath tank.
Separation of glass plates and polymer plate in water bath tank.

Section III

Optical inspection of polymer plates.
Calibration (thickness control).
Paper covering with fish glue.
Size cutting.
Elimination of static electricity.
Storage.

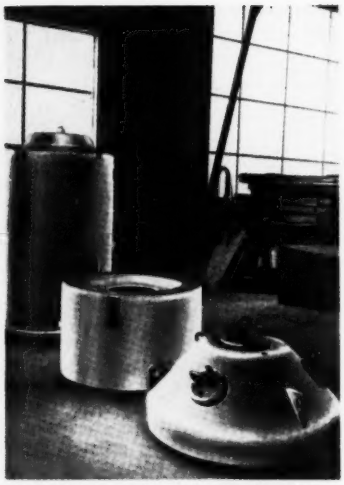
Section IV

Thermic depolymerization (cracking) of scrap.
Distillation of monomer provenant from cracking.

When gases, liquids or solids are irradiated by high-energy radiation many chemical as well as physical changes can occur. The intensity and type of radiation, the presence of specific activators and reactants, the structure of the substance, the medium in which the irradiation takes place, and duration of irradiation are some of the important factors which affect these changes.

When considering the possibilities of applying high-energy radiation in chemical processes, chain processes should be singled out into a special group since, energetically, they differ from others in that comparatively small portions of the energy transferred cause considerable chemical effects.

Among the different highly efficient chain processes, radiation polymerization deserves especial attention.



Five kilocurie Co60 gamma irradiator (*from left to right*): source container, irradiation zone with shielded mantle, couvercle

This is due to the following: (1) radiation polymerization plays a leading part in the general problem of applying nuclear radiation, due to its significance and the degree of elaboration; and (2) the considerable extent to which it has been studied makes it one of the most convenient means of solving problems connected with the mechanism of the initiation of chain reactions, in which the peculiarities of radiation effect are revealed. Research has shown that the processes of radiation polymerization follow the free radical chain mechanism.

The propagation, termination, transfer and branching of reaction chains obey the same general regularities, irrespective of the method of initiation: photo-, radiation- (γ-quanta, α- and β-particles), peroxide-, diazocompound-, redox system- and other types of initiation.

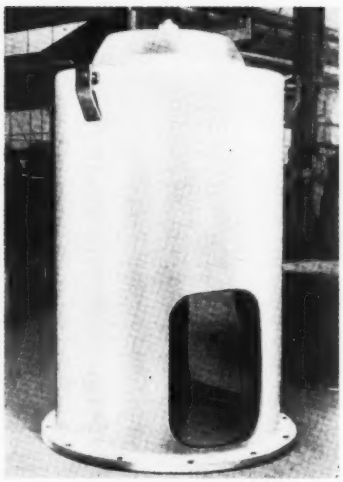
Some specific features of the radiation-chemical processes, depending on the type of radiation (ion concentration in the track of ionizing particles or quanta, the spatial distribution of active particles, etc.) have little effect on these reactions. It should be emphasized that the great number of investigations using radiation initiation of polymerization did not reveal to any noticeable degree ion chains in radiation-chemical conditions. This is evidently explained by the short life time of ions which, though compatible with the duration of an elementary act, is not sufficient to develop chains.

The detailed mechanism of the generation of free radicals under the action of ionizing radiations is not quite clear as yet, except for a few of the simplest systems.

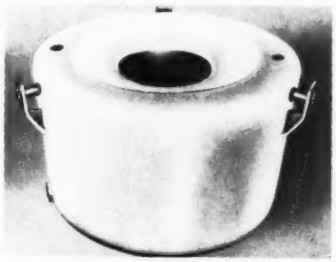
It is known that in the interaction of radiation with a substance, excited molecules are formed along with the ions. Under the direct action of a charged particle, lower energetic states arise within the medium, which are similar to those in the case of photo excitation. The formation of molecules with a higher degree of excitation results from electron capture by the positive ion produced either directly or as a negative ion.

In the processes of generation of free radicals from unsaturated organic compounds (monomers) under the action of ionizing radiation, a significant role is evidently played by excited molecules. Several facts point to analogous regularities in chain processes initiated by photo- and ionizing-radiation.

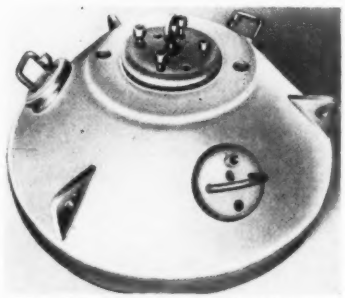
In high-energy irradiation of individual unsaturated compounds, taking into consideration the part played by triplet states (characteristic of the corresponding photo-processes) in the generation of free radicals, the latter are produced from the excited molecules by dissociative reactions. A characteristic feature of such radiations is that under their action states arise which are free of the ordinary photochemical limitations (*e.g.*, optically forbidden transitions). Therefore, as can be seen from the comparison of free radical yields of some monomers in light and γ-quantum irradiation, in the latter case the dependence of free radical yield on the structure of the monomers is manifested to a considerably lesser extent. The sequence of the monomers in respect of their relative efficiency in the corresponding rows also varies, as shown below:—



Five kC Co60 gamma irradiator—source container



Five kC Co60 gamma irradiator—irradiation zone with shielding mantle

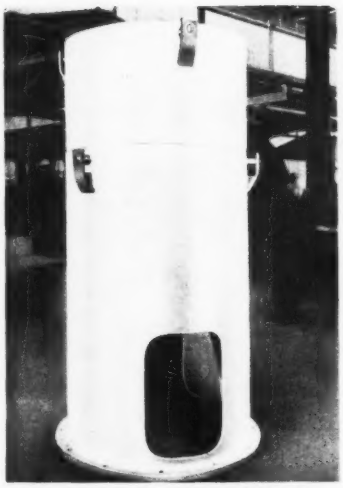


Five kC Co60 gamma irradiator—couvercle with connection flanges

Free Radical Yields in Photo- and Radiation-initiation of Some Monomers (in bulk)

Monomer	G_R	*Relative yield: G_R for styrene is unit*	B	*Relative yield: B for styrene is unit*
Styrene	0.4	1	0.001	1
Styrene	0.6			
Methyl methacrylate	4.0	8	0.12	120
" "	7.0	14		
" "	5.5	11		
Methyl acrylate			0.13	130
Vinyl acetate	8.0	16	0.003	3
α-methyl styrene			5×10^{-3}	5
Isoprene			1×10^{-1}	10
Vinyl butyl ether	4.8	9.6	does not polymerize	

B = number of radicals/quantum of light absorbed.
λ = 303 – 313 mμ
G_R = number of radicals/100 eV.



Five kC Co60 gamma irradiator—source container (*bottom*) and irradiation zone with shielding mantle (*top*)

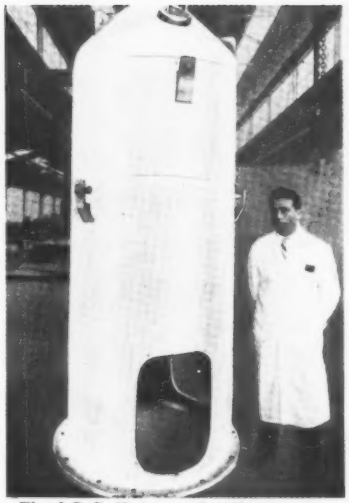
The specific properties of ionizing radiations as generators of free radicals manifest themselves especially with regard to photochemically inactive organic compounds which are indifferent solvents in photochemical systems.

The basic advantages of radiation polymerization as compared to the conventional methods are: (1) the possibility of polymerizing without "substance" initiators, or of using as initiators a large assortment of organic substances available, including solvents, which do not require special production units for their synthesis; (2) the possibility, in principle, of polymerizing monomers which polymerize with difficulty or fail to polymerize at all under ordinary conditions or require complicated polymerization installations; (3) the ease of controlling the initiation rate during the polymerization process; (4) the possibility of achieving high polymerization rates at ordinary or low temperatures or ordinary or low pressures and in non-polar media; and (5) simplifying the design, engineering and conception of the polymerization installation with a considerable saving of material and thus decreasing capital investment for the polymerization plant.

It should be borne in mind, however, that under long exposures and in the case of accumulation of the polymer in the system irradiated due to the direct effect of radiation on the forming polymer, processes arise which lead to the formation of branched or crosslinked polymers, and in some cases, to the opposite, *i.e.*, decomposition and destruction of the polymer. To suppress these harmful phenomena, the duration of irradiation must agree with the rate of these processes, and the polymers formed must be removed from the irradiation zone accordingly.

The general radiation polymerization theory is based upon the production of free radicals when striking the monomer molecule. Initiation of monomer polymerization, propagation of the chain and subsequent termination of the chain occurs in sequence. This is over-simplification as it must be realized that the process is complex and not fully understood.

As a general explanation, one might consider the following to take place:—



Five kC Co60 gamma irradiator—complete (size comparison) weight approx. 30 tons

(1) Formation of ionized and/or excited molecules. The former can also react further with the electron produced in the ionization stage to form the latter as shown below:—

$$M + \text{radiation} \longrightarrow M^{+} \text{ (ionized molecule)} + e \text{ (electron)} + e \text{ (electron)}$$

$$\text{(molecule)} \longrightarrow \overset{\cdot}{M}{}^{*} \text{ (excited molecule)}$$

(2) Decomposition of excited and/or ionized molecules to form free radicals:—

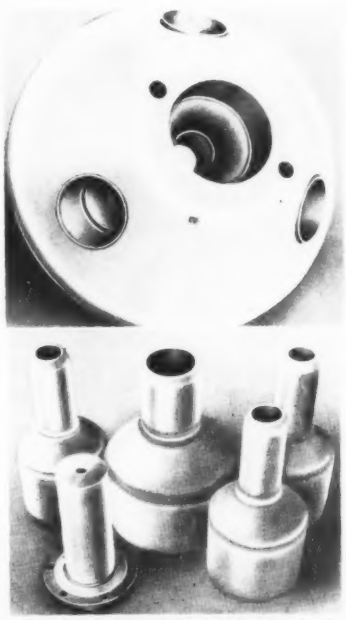
$$M^{*} \text{ (excited molecule)} \longrightarrow R + R' \text{ (free radical where } R' \text{ is remainder of molecule } M\text{, when } R \text{ is separated)}$$

$$M^{+} \text{ (ionized molecule)} + e \text{ (electron)} \longrightarrow R'' + R''' \text{ (free radicals formed by preferential scission of molecule)}$$

(3) The formation of these free radicals (R, R', R'', R''') serves as a site for chain growth to occur (propagation) and for subsequent chain termination. An example for the monomer, acrylonitrile ($CH_2 = CHCN$) follows:—

$$CH_2 = CH - CN \xrightarrow{(R + R')} R - (CH_2 - \underset{\displaystyle CN}{\underset{|}{CH}} -)_n - R'$$

$$CH_2 = CH - CN \xrightarrow[(R'' + R''')]{} R'' - (CH_2 - \underset{\displaystyle CN}{\underset{|}{CH}} -)_n - R'''$$

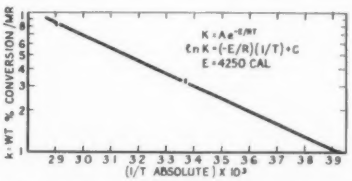


Five kC Co60 gamma irradiator—(*top*) covercle, (*bottom*) connection flanges

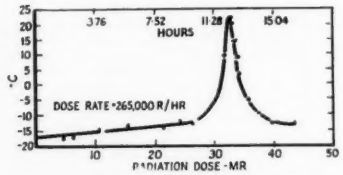
When using alpha-particles for irradiation, various monomers are to be expected, with different rates of polymerization. To specific monomers may be assigned constants, when using alpha-radiation, as shown below:—

Monomer	*Rate per cent. Conversion to Polymer*
Butadiene	5×10^{-2}
Styrene	0.7
Acrylonitrile	3.2
Methyl methacrylate	24.0
Vinyl acetate	42.0

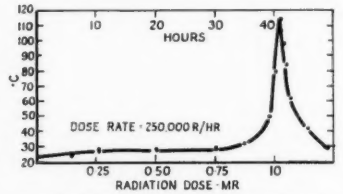
When using gamma radiation for irradiation, the following rate



Rate of methyl methacrylate polymerization *vs* reciprocal temperature



Temperature during methyl methacrylate polymerization at −18° C.



Temperature during methyl methacrylate polymerization at room temperature

constants (expressed in moles/litre/sec) may be assigned to specific monomers:

Monomer	*Constant*
Butadiene	1
Styrene	2
Acrylonitrile	5
Methyl methacrylate	24
Vinyl chloride	63
Methylacrylate	76
Vinyl acetate	135

Although the above data gives a relative idea about the ease of polymerization of specific monomers, there are other complications.

The gamma-ray induced polymerization of methyl methacrylate is of a free radical nature. The monomer shows a constant rate of polymerization in the initial stage followed by a rapid increase similar to a " Trommsdorf " effect. Molecular weight increase occurs with the increased rate. There is some indication of surface effect on polymerization rate and of crosslinking of polymer. The activation energy for methyl methacrylate polymerization is 4.25 kcal/M. Methyl methacrylate is much easier to polymerize than acrylonitrile or styrene (about 10 times faster). The increase in polymerization rate of methyl methacrylate occurring between 20 and 40 per cent. conversion is remarkable. The temperature increase of 100°C. at room temperature is due to combination of thermal and viscosity effects. The molecular weights also increase with the rise in polymerization rate.

The variation in molecular weight with temperature is different from that observed in thermal polymerization. In thermal polymerization the molecular weight varies inversely with temperature, whereas in the radiation-induced polymerization the molecular weight varies with temperature. This is attributed to the fact that rate of radical production is not affected over the temperature range applied to the radiation polymerization process; the propagation step is speeded up, and an overall effect of higher molecular weight results at the higher temperature.

The experimental yield of free radicals in aliphatic hydrocarbons amounts to approximately 6 radicals/100 eV of irradiated energy. Consequently some 370 kcal radiation energy are required to produce 1 mol of radicals. A gamma radiation source of 20 curies produces in hydrocarbons in 1 minute and in one metre of distance a radiation dose of 1 roentgen. This corresponds to an energy absorption of 93 erg/g or 5.8×10^{13} eV/g. Thus such a comparatively small radiation source may produce $6 \times 5.8 \times 10^{13}/100 = 35 \times 10^{11}$ radicals/min and per g of matter.

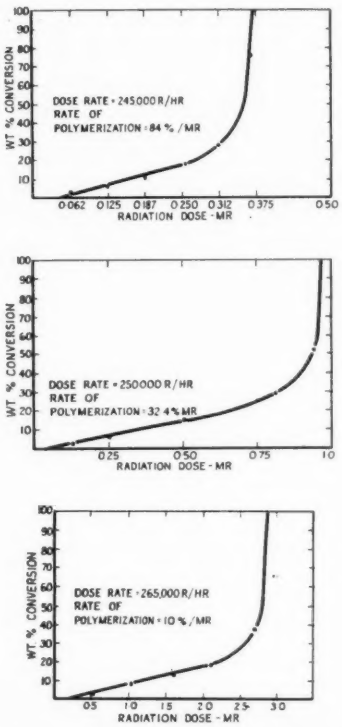
In an irradiation zone some 20 cm high and 50 cm in diameter some

Table IV.—Methyl Methacrylate Polymerization at −18° C.
Dose Rate—265,000 r/hr; Polymerization Rate, $k = 10$ per cent. conversion/Mr

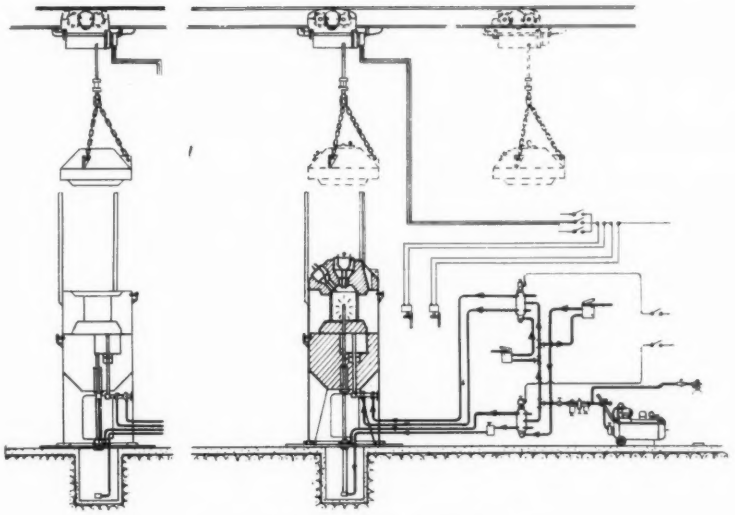
Irradiation time (hr)	Irradiation Dose (Mr)	Conversion (wt per cent.)	Av. Molecular weight
1	0.26	0.8	—
2	0.53	2.75	68,500
4	1.06	8.17	73,000
6	1.59	13.34	73,000
8	2.12	18.47	153,000
10.2	2.70	38.4	—
10.75	2.85	—	850,000
11.5	3.05	100.00	—
13.1	3.47	100.00	427,000

Table V.—Methyl Methacrylate Polymerization at Room Temperature
Dose Rate—250,000 r/hr; Polymerization Rate, $k = 32.4$ per cent. conversion/Mr

Irradiation time (hr)	Irradiation dose (Mr)	Conversion (wt. per cent.)	Av. Molecular weight
0.25	0.06	0.97	160,000
0.50	0.12	2.96	159,000
1.0	0.25	6.50	163,000
2.0	0.50	14.60	164,000
3.0	0.75	27.25	—
3.25	0.81	30.57	242,000
3.50	0.87	34.50	312,000
3.75	0.94	52.55	572,000
4.00	1.0	99.8	783,000



Polymerization of methyl methacrylate at −18° C. (*top*), room temperature (*middle*) and at 70 C. (*bottom*)



Schematic drawing of the gamma irradiator

4 tons of methyl methacrylate can be polymerized at 20°C. and some 20 tons at 60°C. by a gamma radiation source of 100 curies.

Gamma-ray induced polymerization differs significantly from polymerizations effected with thermal, catalytic or ultra-violet sources. The polymers produced do not obey the usual viscosity molecular weight relationships, and this may be reflected in different physical properties.

The significant features of gamma-ray induced polymerization are:—(1) polymerization can be realized at low temperatures; (2) no foreign substances are added to the polymerizing mixture; (3) monomers which are heat-sensitive may conceivably be polymerized without adverse thermal effects; (4) the possibility of solid state polymerization; (5) crosslinkage between linear polymers may be achieved without crosslinking agents since the gamma rays are capable of forming active centres along the polymer chain; (6) previously unreacted monomers may be induced to polymerize; (7) radiation-induced polymerization has all the advantages of ultra-violet initiation, such as being temperature independent in the initiation step and not requiring the addition of foreign substances, as well as the penetration power lacking in ultra-violet; (8) molecular weight control by temperature change can be achieved over a wide range since the initiation step is temperature independent.

In this particular case, radiation induced polymerization of methyl methacrylate monomer has a unique advantage over conventional methods of thermal and catalytic polymerization in avoiding adverse thermal effects on the considerably heat sensitive monomer. In conventional processes the polymerization initiation is achieved in the so-called pre-polymerization by boiling of the monomer over a period of some 5 to 10 minutes. This initial thermal exposure of the heat-sensitive monomer is responsible for a rather violent further continuation of the polymerization and for any irregularities and difficulties which may easily be encountered during conventional thermal and catalytic polymerization of the methyl methacrylate monomer. By the radiation initiation of polymerization at room temperature, the thermal stress on the heat-sensitive monomer is avoided and the conventional difficulties during the final polymerization eliminated.

Table VI.—Methyl Methacrylate Polymerization at 70°C.

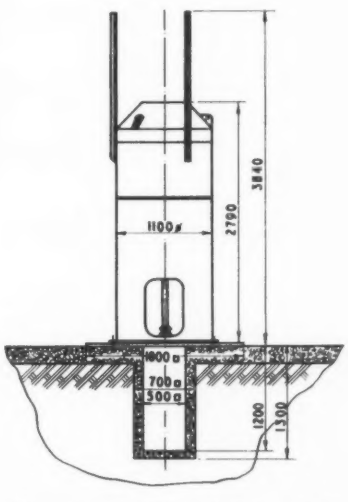
Dose Rate—245,000 r/hr; Polymerization Rate, k = 84 per cent. conversion/Mr

Irradiation time (hr)	Irradiation dose (Mr)	Conversion (wt. per cent.)	Av. Molecular weight
0.25	0.06	2.1	70,000
0.5	0.122	6.1	125,000
0.75	0.184	11.1	200,000
1.05	0.256	18.5	260,000
1.25	0.306	28.0	300,000
1.5	0.367	74.7	370,000
2.0	0.490	100.0	380,000

Pumping

The filtered monomer, according to the various qualities required with an addition of plasticizer and pigments, is continuously pumped through a multiple coil around a vertically arranged multikilocurie Co60 gamma source which is completely shielded by a 35 cm thick lead shield. The flux velocity of the liquid monomer is regulated and controlled automatically according to the intensity and dose rate of the gamma source to enable an integral irradiation of the dose required. This radiation initiation occurs at room temperature and consequently without thermal stress on the heat-sensitive monomer. By this radiation initiation of polymerization free radicals are formed in the monomer, in a sufficient quantity to induce polymerization.

The container with the gamma source comprising the irradiation



Dimensions of a 5 kilocurie Co60 gamma irradiator

zone is completely self-contained and may be erected in the plant without any additional radiation protection as the surface dose rate is less than 2 mr/hr and thus within the limits of the tolerance dose.

Initial production capacity of the plant is set at 50 tons/month, the complete design has been made for a total production of 200 tons of finished product/month, to be reached within two years of the plant starting up, which is scheduled for the end of 1961. This will be the first time that industrial polymerization has been practically realized. By 1962 production will have overcome the laboratory stage and thus opened up vast new possibilities in the organic chemical industry.

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Institution News

Midland Branch Meeting
Pinkerton Founder Award
Two more papers

INSTITUTION activity and membership are growing at an encouraging rate, about that there can be no doubt. Especially encouraging are the measures being taken to provide local activities for Members in the Provinces. The highly successful meeting held by the Midland Branch on March 28th is an example of what can be done. Mr. H. F. Jones was in the chair and the meeting was well attended.

Members present heard an interesting lecture by Mr. K. J. Durrands in which he gave a brief history of reactor development and examined lessons learnt from early reactors; in addition to this he described changes in turbine thermodynamic cycles and gave reasons for these changes. Mr. Durrands also showed three films entitled "How a thermal reactor works," "Principles of nuclear fission," and "Nuclear power in Britain." These films were shown by permission of the UKAEA Public Relations Branch. The lecture was followed by a lively discussion.

Names were taken at this meeting of Members willing to serve on the Midland Branch Committee. Additional names may be submitted at the next Branch meeting when six Members will be elected to form the committee.

100 guineas Award

The Council has decided that the 100 guineas award which is to be presented annually shall in future be known as the Pinkerton Founder Award. The two papers which share the award for this year will be presented at Caxton Hall, London as follows, "The Siting of Nuclear Power Reactors in the U.K." by A. Quinton, at 6.30 p.m. on May 2nd and "Electric Power from Nuclear Heat —Direct" by J. W. Gardner at 6.30 p.m. on May 9th. Mr. Quinton will present his own paper but Dr. Grassam will present that by Mr. Gardner.

Count Zoppi, the Italian Ambassador in London, has expressed his "warmest appreciation" to the Council and President for nominating him as the first Honorary Member of the Institution.

An entrance examination is to be introduced for Junior Members of the Institution. Dr. Grassam will assume responsibility for this.

Provisional arrangements have been made for two papers to be presented in November and December of this year. The first will be given by Dr. Paulsen on "Teaching" and the second by Captain Atkins of Vickers on "Nuclear Marine Propulsion."

Journal Exchange

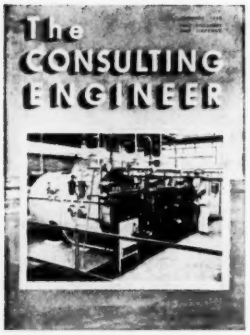
An exchange has now been arranged between NUCLEAR ENERGY and ATOMNAYA ENERGIYA. In a letter to the Institution the Chief Editor of ATOMNAYA ENERGIYA says, "I hope that the exchange of our journals will promote mutual understanding between the scientists of our two countries." ATOMNAYA ENERGIYA is the official journal of the Soviet Academy of Sciences, State Committee of the Soviet of Ministers of the U.S.S.R. for the utilization of atomic energy. △△△

NEW MEMBERS—*Elected April 5th, 1961*

Mohamed Fadhil Al-Kazily, Baghdad, Iraq.	AM	W. K. Curtis, Abingdon Berks.	M	T. L. Farragher, Whitehaven.	M	A. B. A. Pereira, Zanzibar.	JM
P. D. Allen, Birmingham.	M	F. J. Brand, London.	M	J. R. H. Glen, Castle Bromwich.	AM	J. K. Platt, Birmingham.	AM
Robert Barnes, Southminster.	M	P. D. Marshall, Southend-on-Sea.	JM	H. P. Powell, Birmingham.	JM	J. P. Paul, Chislehurst.	M
M. V. Bradbury, Stourbridge.	AM	P. Davies, Birmingham.	M	M. D. Haslam, Hemel Hempstead.	M	M. A. Rickards, Tipton, Staffs.	JM
H. C. Dent, Gillingham.	AM	B. B. Farmer, Birmingham.	AM	P. Hazleman, Chelmsford.	M	T. V. Tuft, Brewood, Staffs.	AM
				D. Oliver, Swindon.	M	A. N. White, Basingstoke.	AM

Elected March 20th, 1961

L. A. W. Bedford, Reading.	A	D. S. Harris, Birmingham, 24.	A	A. R. Myhill, Birmingham, 24.	M	P. B. Spencer, Sutton Coldfield.	JM
G. I. Chambers, Burnham on Crouch	A	H. L. Harris, Castle Bromwich.	JM	T. J. K. Parker, Castle Bromwich.	A	B. W. Storey, Derby.	A
G. B. Clark, Maldon.	A	A. J. Hughes, Castle Donington, Derby.	A	M. A. Paxton, Littleover, Derby.	A	R. J. Taylor, Reading, Berks.	A
M. G. Collishaw, Birmingham, 23.	JM	Roberto Kaysert, Denmark	M	M. K. Pratt, Slough, Bucks.	A	F. J. Wood, Wednesfield. Staffs.	A
T. G. F. Crick, Birmingham, 16.	A	R. T. S. Locock, Barrow-in-Furness	A	G. R. Ricketts, Birmingham, 34,	A	Alan Williams, Birmingham, 14.	JM
K. J. Durrands, Birmingham.	M	M. T. Lowcock, Barton on Sea, Hants.	A	Alan Sayers, Luton, Beds.	A	Ronald Wilson, Southminster, Essex.	A
Ronald Filkin, Southampton.	A	J. B. McFarlane, Bridgwater.	A	T. G. G. Smith, Newbury, Berks.	M	Keith Wright, Shenstone, Staffs.	JM
C. J. Fox, Sutton Coldfield.	JM	A. E. Martin. Birmingham, 10.	JM				



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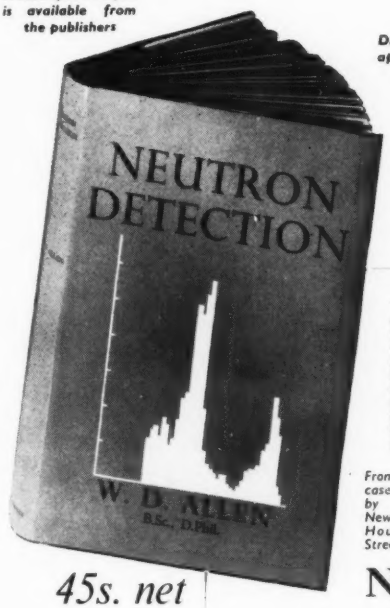

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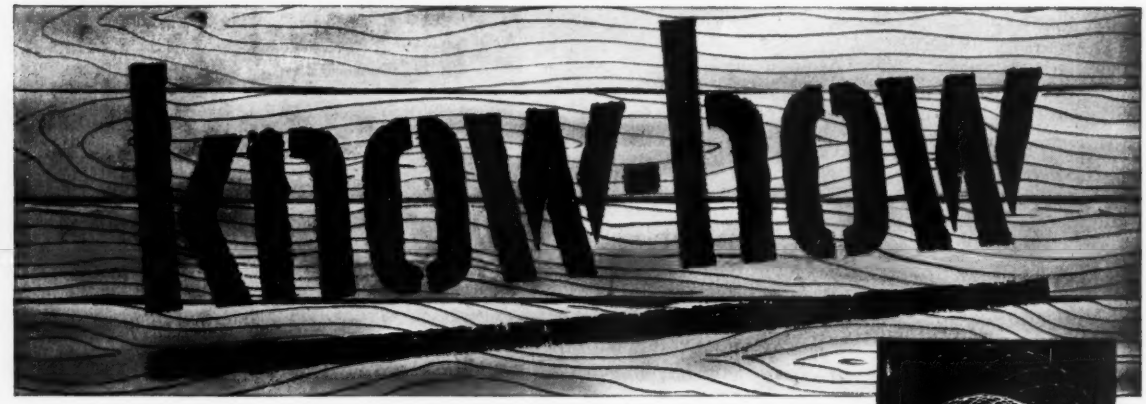

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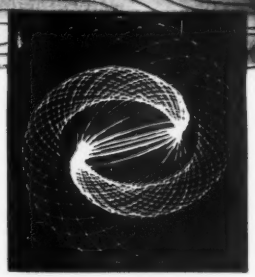

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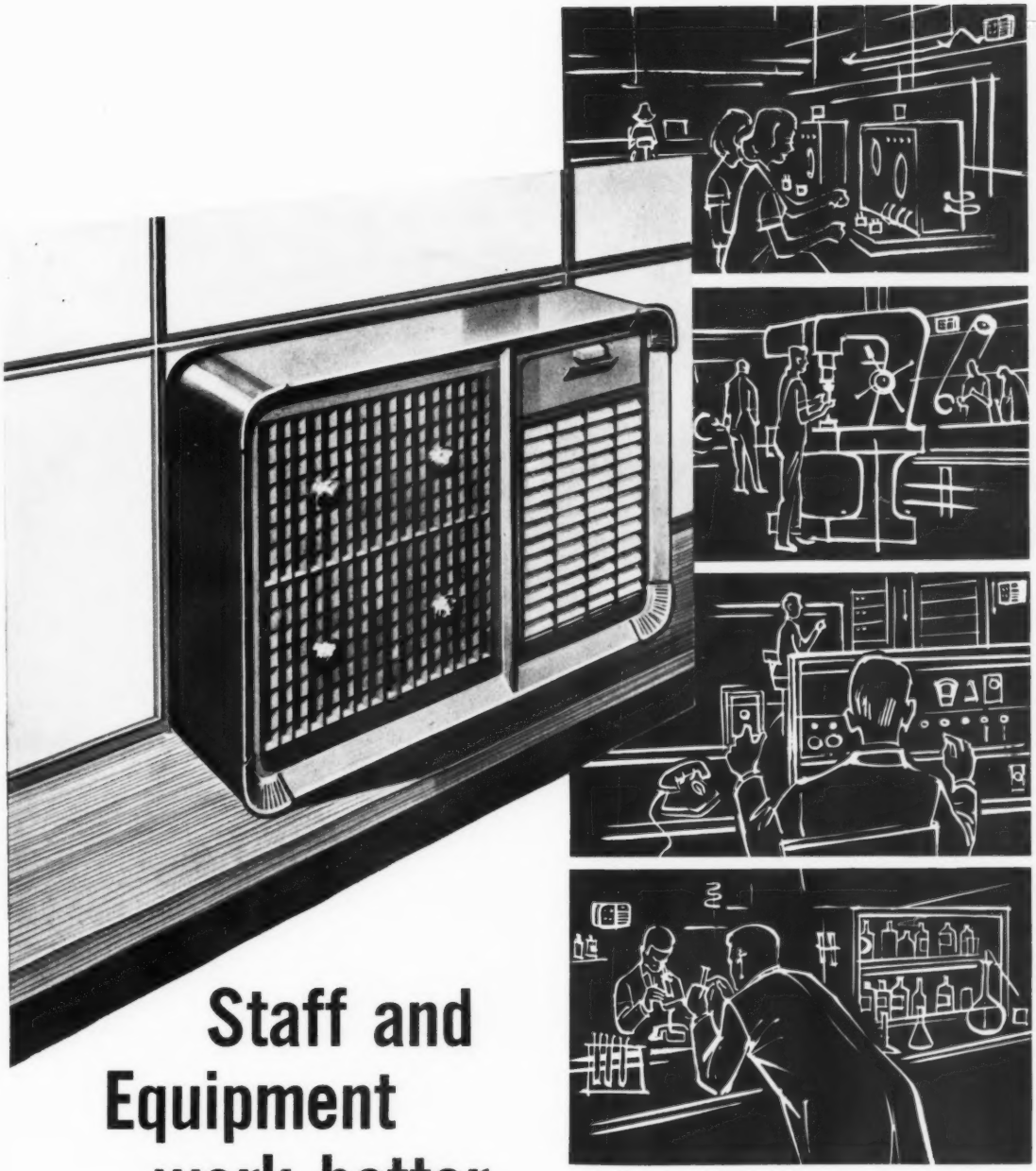

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